PB-251 619

GUIDELINES FOR AIR QUALITY MAINTENANCE PLANNING AND ANALYSIS. VOLUME 9. EVALUATING INDIRECT SOURCES

Environmental Protection Agency
Research Triangle Park, North Carolina

January 1975

DISTRIBUTED BY:

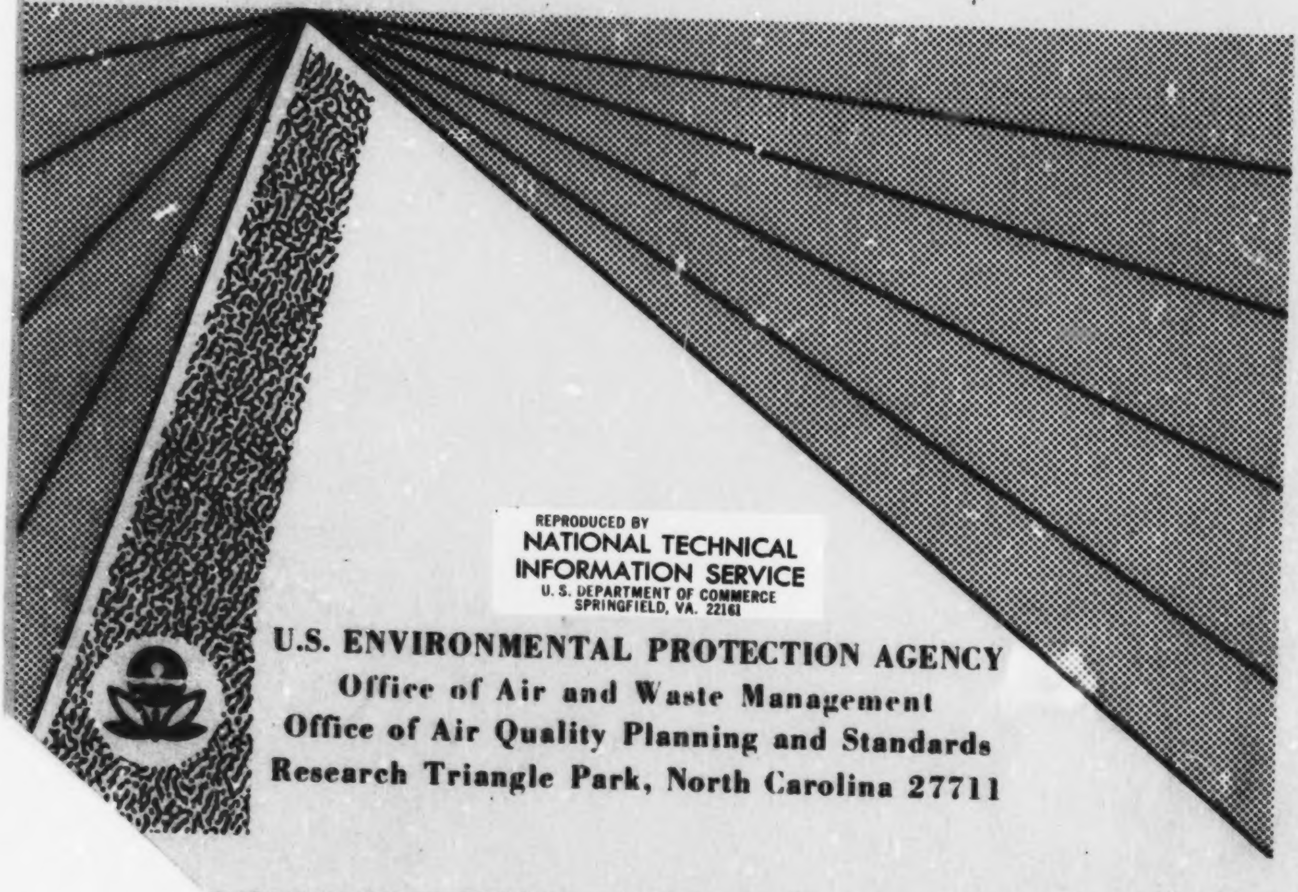
NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

106022

EPA-450/4-75-001
January 1975
(OAQPS NO. 1.2-028)

PB 251 619

GUIDELINES FOR AIR QUALITY MAINTENANCE PLANNING AND ANALYSIS
VOLUME 9 :
EVALUATING INDIRECT SOURCES



REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-450/4-75-001	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Guidelines for Air Quality Maintenance Planning and Analysis Volume 9: Evaluating Indirect Sources		5. REPORT DATE January 1975 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Research Triangle Park, N. C. 27711		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Research Triangle Park, N. C. 27711		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This document has been prepared to serve the user in responding to air quality maintenance, indirect source, and parking management regulations.

16. ABSTRACT

In formulating and implementing an air quality maintenance plan, it may frequently be desirable to include provisions for new source review. One type of new source is the indirect source. This document presents a screening procedure that may be useful in assessing the maximum impact of a proposed indirect source on roadside concentrations of carbon monoxide. The screening procedure is intended to be conservative so that if no potential problem is identified, there may be reasonable assurance that none will occur. Specific suggestions are made concerning estimation of carbon monoxide (CO) concentrations in the vicinity of signalized and unsignalized intersections as well as near locations where traffic is freely flowing. More detailed discussions concerning the estimation of emissions of CO in and around parking lots are contained in appendices to the document. Further discussions of techniques relating emissions to ambient 1- and 8-hour CO concentrations also appear in the appendices.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Airborne Wastes Atmosphere Contamination Control Traffic Engineering Vehicular Traffic Atmospheric Models Carbon Monoxide	Air Quality Maintenance Indirect Sources Indirect Source Review Relationships between traffic and nearby Air Quality	13/02

PRICES SUBJECT TO CHANGE

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 509
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE $12.75

EPA Form 2220-1 (9-73)

EPA-450/4-75-001
(OAQPS NO. 1.2-028)

GUIDELINES FOR AIR QUALITY MAINTENANCE PLANNING AND ANALYSIS
VOLUME 9 :
EVALUATING INDIRECT SOURCES

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711
January 1975

OAQPS GUIDELINES SERIES

This report is one of the guidelines series of reports issued by the Environmental Protection Agency, Office of Air Quality Planning and Standards (OAQPS), to provide information on air quality maintenance to state and local air pollution control agencies. Copies are available free of charge to Federal employees, current contractors, grantees, and nonprofit organizations, as supplies permit, from the Air Pollution Technical Information Center, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, or at a nominal cost from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Publication No. EPA-450/4-75-001
(OAQPS Guideline No. 1.2-028)

FOREWORD

This document is the ninth in a series comprising Guidelines for Air Quality Maintenance Planning and Analysis. The intent of the series is to provide State and local agencies with information and guidance for the preparation of Air Quality Maintenance Plans required under 40 CFR 51. The volumes in this series are:

Volume 1: Designation of Air Quality Maintenance Areas
Volume 2: Plan Preparation
Volume 3: Control Strategies
Volume 4: Land Use and Transportation Consideration
Volume 5: Case Studies in Plan Development
Volume 6: Overview of Air Quality Maintenance Area Analysis
Volume 7: Projecting County Emissions
Volume 8: Computer-Assisted Area Source Emissions Gridding Procedure
Volume 9: Evaluating Indirect Sources
Volume 10: Reviewing New Stationary Sources
Volume 11: Air Quality Monitoring and Data Analysis
Volume 12: Applying Atmospheric Simulation Models to Air Quality Maintenance Areas
Volume 13: Allocating Projected Emissions to Sub-County Areas

Additional volumes may be issued.

All references to 40 CFR Part 51 in this document are to the regulations as amended through July 1974.

These guidelines are intended to provide a screening technique for evaluating proposed indirect sources. If a more detailed analysis is warranted or desired, it is suggested that the appendices to the guidelines be consulted. This document supersedes "Interim Guidelines for the Review of the Impact of Indirect Sources on Ambient Air Quality" (July 1974). The information in this volume is being published at this time primarily to assist those persons having responsibility for estimating roadside carbon monoxide (CO) concentrations as the result of requirements imposed by environmental impact statement analysis and review and analysis for air quality maintenance plans. Further, this document is believed to represent a substantial improvement over the interim guidelines.

It is anticipated that the guidance in this document will be very similar to guidelines which will be proposed in the Federal Register concerning the CO review suggested by Indirect Source and Parking Management Regulations. The proposed guidelines will appear in the Federal Register prior to the effective date of the regulations (currently July 1, 1975). The proposal will then be subject to further change upon receipt and evaluation of comments from the public prior to publication in the Federal Register in final form. In the event of inconsistencies between the guidance in this document (EPA-450/4-75-001) and that published in the Federal Register in proposed and final form, the guidance in the Federal Register should take precedence.

PREFACE

These indirect source technical review guidelines have been prepared in response to two regulations recently promulgated or proposed by the U. S. Environmental Protection Agency (EPA). First, the guidelines may be used as one possible means for estimating the impact of a proposed source on ambient air quality pursuant to regulations for the "Review of Indirect Sources" (40 CFR 52.22(b)) promulgated on July 9, 1974.[1] Although the guidelines contain some discussion concerning estimation of emissions of hydrocarbons and oxides of nitrogen, the major thrust is directed toward the review of a proposed facility's impact on ambient concentrations of carbon monoxide (CO). The present analytical capability for simulating the complex interrelationships among hydrocarbons, oxides of nitrogen, oxidants, ambient aerosols, humidity and sunlight does not permit presentation in a general guideline document of a detailed, quantitative technique for evaluating the impact of an individual source on ambient concentrations of photochemical pollutants. In areas where the validity of a photochemical dispersion model has been demonstrated, the use of such a model to evaluate the impact of major highway systems or large regional airports is encouraged. Frequently, however, such models will not be available and it will be necessary to rely on less precise approaches for protecting the public against adverse levels of oxidants, nitrogen oxides and hydrocarbons. Although methods

Preceding page blank

of analysis may be less detailed than is desirable for photochemical pollutants, such approaches as are available may nevertheless indicate the degree of control needed for broad-scale management of air quality. Regulations concerning the "Maintenance of National Ambient Air Quality Standards" (40 CFR 51.12), proposed by EPA on June 18, 1973,[3] address the need for management of regional air resources. A series of guideline documents[4-16] have been published describing intergovernmental coordination, land use and transportation planning and analytical techniques needed to support development of an effective regional air quality maintenance plan. Indirect source review, as presented in these guidelines, may be thought of as a tactic to be employed within a comprehensive air quality maintenance plan. These indirect source review guidelines serve as Volume 9 of the previously referenced Air Quality Maintenance Planning and Analysis Guidelines. In addition to the development of techniques for evaluation of air quality maintenance plans, there are two additional means whereby the impact of proposed facilities on regional hydrocarbon, nitrogen oxide and oxidant problems may be estimated. The first is presented in the proposed parking management regulations[2] in which qualitative means for assessing a proposed parking facility's impact on vehicle miles traveled (VMT) are presented. The second means addresses problems presented by highway systems in meeting photochemical oxidant and nitrogen dioxide standards using existing predictive models.[17]

The indirect source review guidelines described in this volume are organized as follows. A screening procedure for estimating peak CO concentrations associated with identified traffic design and operating variables is first presented. These estimates are then compared with the National Ambient Air Quality Standards (NAAQS) for carbon monoxide of 40 mg/m^3 (35 ppm) for 1-hour averaging times and 10 mg/m^3 (9 ppm) for 8-hour averaging times. If the results indicate there may be difficulty in meeting the 1- or 8-hour NAAQS for CO, this is not necessarily grounds for denial of a permit for construction of the source. The screening technique is intended to be conservative so that situations in which a potential problem may exist can be identified. Should such a problem be indicated, the options for redesign of the facility and reapplication of the screening procedure, or for a more complete analysis should be offered. It is not necessary to refer to any of the appendices to the guidelines unless:

1. Specified key determinants of emissions are not adequately provided;

2. The assumptions which were made in developing the screening procedure are clearly not applicable; or

3. There is a desire on the part of the applicant or review agency to perform a more complete analysis.

Appendices A through G to the guidelines present more complete methodologies which can be used to estimate emissions from each of seven types of indirect source. For the most part, it should only be necessary to refer to the single appendix which is applicable for the source category being reviewed to estimate emissions. The exception to this is Appendix A which may be used in estimating emissions from access roads, arterial streets and at intersections in the vicinity of other types of indirect sources.

There are several types of indirect sources mentioned in the indirect source review regulations[1] (i.e., industrial and entertainment facilities, office and government buildings and apartment and condominium buildings) which are not specifically discussed in Appendices A-G. The procedures for estimating traffic volume demand for each of these resemble the one in Appendix E for parking facilities where annual average daily traffic is a function of the facility's size. If traffic is more or less continuous, the method in Appendix E for estimating emission factors, running times and queue lengths may be used. If the facility is an event-oriented one (e.g., entertainment facility, industrial facility with shift work), the guidance in Appendix D (sports complexes) may be used to estimate running times, emission factors and emissions. Appendix H presents more detailed procedures which might be employed in estimating the impact of the source on air quality. Appendix I is a partial compilation of previous monitoring studies in the vicinity of indirect sources. The purpose of Appendix I is to provide applicants and reviewers with potential additional sources of information.

TABLE OF CONTENTS

Page

List of Figures xi

List of Tables xii

List of Abbreviations and Symbols xiii

1.0 Introduction 1

2.0 Rationale for a Screening Procedure 2

3.0 Definitions 5

4.0 Screening Procedure for Reviewing the Impact of a Proposed Indirect Source on Ambient Concentrations of CO 14

- 4.1 Impact of Traffic on Nearby 1-hr CO Concentrations 15
  - 4.1.1 Freely Flowing Traffic 15
  - 4.1.2 Traffic at Signalized Intersections 16
  - 4.1.3 Traffic at Tollbooths and Unsignalized Intersections 18
  - 4.1.4 Estimating Representative Concentrations on Sidewalks 19
- 4.2 Impact of Traffic on Nearby 8-hr CO Concentrations 20
- 4.3 Estimation of Background CO Concentrations 32
  - 4.3.1 Seasonal Adjustment of Observed Concentrations 34
  - 4.3.2 Interpretation and Use of Monitoring Data at Proximate and Representative Sites 36
  - 4.3.3 Estimating the Impact of Remote Sources within a Proposed Parking Lot 38
- 4.4 The Effect of Varying Automotive Operating Factors 39
  - 4.4.1 Fraction of Vehicles Operating from a Cold Start 39
  - 4.4.2 The Effect of Automotive Emission Control Programs 41
  - 4.4.3 Consideration of Other Factors Affecting Local Vehicle Operating Conditions 43
- 4.5 Special Considerations for Event-Oriented Facilities 44
- 4.6 Illustrative Examples of the Application of the Screening Procedure in Indirect Source Review 45

Page

4.7 Summary of the Screening Procedure 74

5.0 Economic and Design Considerations 79

5.1 Data Acquisition and Application Costs 80

5.2 Time-Related Costs 80

5.3 Design Changes 81

6.0 Assumptions Used in the Screening Procedure 85

6.1 Meteorological Assumptions 86

6.2 Emission Assumptions 92

6.3 Traffic Assumptions 97

6.4 Assumptions Used in Evaluating Background Concentrations 103

7.0 References 104

Appendix A. Methods for Estimating Emissions from Highways A-i

Appendix B. Method for Estimating Ground Traffic Emissions from Airports B-i

Appendix C. Methods for Estimating Emissions in Vicinity of Regional Shopping Centers C-i

Appendix D. Methods for Estimating Emissions in Vicinity of Sports Complexes D-i

Appendix E. Method for Estimating Emissions in Vicinity of Municipal Parking Lots E-i

Appendix F. Method for Estimating Emissions at Amusement Parks F-i

Appendix G. Method for Estimating Emissions at Recreational Areas G-i

Appendix H. Use of Dispersion Models to Estimate Air Quality in Vicinity of an Indirect Source H-i

Appendix I. Compilation of Indirect Source Monitoring Studies I-i

LIST OF FIGURES

Figure — Page

1. Key Locations in the Review of a Hypothetical Indirect Source 21
2. Volume Demand-Capacity Ratio in a Freeway or Expressway Lane vs. CO Concentration Impact at a Perpendicular Distance of 10 Meters 22
3. Volume Demand-Capacity Ratio in a Lane on a Major Street vs. CO Concentration Impact at a Perpendicular Distance of 10 Meters 23
4. Volume Demand-Capacity Ratio in a Lane Within an Indirect Source vs. CO Concentration Impact at a Perpendicular Distance of 10 Meters 24
5. Relative Concentration of CO vs. Perpendicular Distance from a Traffic Lane with Freely Flowing Traffic 25
6. Maximum Impact of Traffic in an Approach Lane Upstream from a Signalized Intersection at a Receptor Site Located at a Perpendicular Distance of 10 Meters 26
7. Maximum Impact of Traffic in a Lane Downstream from an Intersection at a Receptor Site Located a Perpendicular Distance of 10 Meters Away 27
8. Relative Concentration of CO vs. Perpendicular Distance from a Traffic Lane Near a Signalized Intersection 28
9. Impact of Traffic Upstream from a Non-Signalized Intersection on CO Concentrations at a Receptor Site Located a Perpendicular Distance of 10 Meters Away 29
10. Relative Concentration of CO vs. Perpendicular Distance from a Traffic Lane Near an Unsignalized Intersection 30
11. Summary of the Indirect Source Screening Procedure 75

LIST OF TABLES

Table — Page

1. COLD START CORRECTION FACTORS AT VARIOUS AMBIENT TEMPERATURES — 40
2. CORRECTION FACTORS REFLECTING EMISSION CONTROL PROGRAMS IN DIFFERENT AREAS — 42
3. ASSUMED OPERATING SPEEDS, LEVELS OF SERVICE AND DEMAND-CAPACITY RATIOS FOR MAJOR STREETS AND CORRESPONDING EMISSION FACTORS FOR FREE FLOW CONDITIONS — 99
4. ASSUMED OPERATING SPEEDS, LEVELS OF SERVICE AND DEMAND-CAPACITY RATIOS FOR URBAN EXPRESSWAYS AND CORRESPONDING EMISSION FACTORS FOR FREE FLOW CONDITIONS — 100
5. ASSUMED OPERATING SPEEDS AND DEMAND-CAPACITY RATIOS FOR TRAFFIC LANES WITHIN INDIRECT SOURCES AND CORRESPONDING EMISSION FACTORS FOR FREE FLOW CONDITIONS — 101

LIST OF ABBREVIATIONS AND SYMBOLS

c	Traffic capacity, vehicles/hour
c_{ij}	Traffic capacity at approach (or road segment) i, lane j, vehicles/hour
c'	Unimpeded capacity at a signalized intersection, vehicles/hour of green time
cf	Correction factor reflecting emission control programs, dimensionless
CPH	Number of signal cycles in an hour
c(s)	Speed correction factor to be applied to emission factors
Cy	Cycle length or the amount of time required for a traffic signal to complete all of its phases, sec.
D	Spacing between the tailpipes of successive vehicles, m
EF	Emission factor, gm/min-veh
ef	Emission factor, gm/mi-veh
G	The amount of time a traffic signal is green during one signal cycle for a specified intersection approach, sec.
G/Cy	Green time to signal cycle ratio, dimensionless
K	Cold start correction factor, dimensionless
L	Length of a queue of vehicles, m
lf	Local factor, the ratio between local CO emission factor and the national average factors, dimensionless
m	Meters
m/sec	Meters per second
mg/m^3	Milligrams per cubic meter
mph	Miles per hour

p	Persistence factor used to account for variations in meteorological conditions over 8 hour periods, dimensionless
ppm	Parts per million, units of concentration
q_{ij}	Emission intensity for road segment (gate) i, lane j, gm/sec-m
S	Vehicle speed, mph
t	Ambient temperature, °F
T_i	Time required to accommodate all vehicles wishing to use gate i at an event-oriented indirect source, hours
v_{ij}	Traffic volume demand at road segment (approach) i, lane j, veh/hr
V'_i	Traffic volume wishing to use gate i at an event-oriented source, vehicles
v/c	Volume demand-capacity ratio, dimensionless
vph	Vehicles per hour
x	Concentration, ppm

1.0 INTRODUCTION

An indirect source is defined as a facility, building, structure or installation which attracts or may attract mobile source activity that results in emissions of a pollutant for which there is a national standard.

A complete analysis of such a facility requires a two-tiered examination of a source's impact. The first tier is regional in scope, and requires a determination of consistency with applicable air quality maintenance plans and transportation control plans. Provisions in "Parking Management Regulations," which require proposed parking facilities in designated parking management areas to reduce vehicle miles traveled (VMT) or to at least minimize increases in VMT, are intended to address regional problems posed by parking facilities. Specific measures to achieve these goals are enumerated in the regulations.[2] Guidelines for the review of the impact of highways and highway systems on ambient oxidant and nitrogen dioxide concentrations are also being prepared. In addition to identifying procedures for estimating the regional impact of such sources, this latter set of guidelines is intended to identify where within the institutionalized Continuing, Comprehensive and Cooperative ("3-C") transportation planning process such a review (required under 23 USC 109(j)) would best be placed.

The second tier of analysis is a microscale one requiring a determination of the impact of a proposed source on ambient air quality at sensitive locations, usually within 1/4 mile of the proposed site. Because of the nature of the criteria pollutants emitted by motor vehicles, most efforts in the second tier of analysis are directed at reviewing the proposed source's impact on ambient carbon monoxide (CO) concentrations. The guidelines described herein are primarily intended to assist indirect source review agencies, applicants and consultants in estimating the impact of a proposed facility on air quality in its vicinity. More explicitly, the purposes of this document are fourfold:

1. To provide means for estimating whether a proposed indirect source may threaten the National Ambient Air Quality Standards (NAAQS) for CO;

2. To provide means whereby the efficacy of good traffic engineering practice in meeting CO standards can be evaluated;

3. To provide a simple screening procedure for review of a source's impact on ambient CO concentrations which can be applied expeditiously, but which can give reasonable assurance that sources which pass the procedure will not threaten the NAAQS for CO; and

4. To provide assistance in estimating the gross hydrocarbon and nitrogen oxide emissions attributable to an individual source so that this information may be used, as needed, in other guideline documents.

2.0 RATIONALE FOR A SCREENING PROCEDURE

Since indirect source review or parking management review requirements may be applicable to a large number of proposed sources, it is highly desirable that a reviewing agency's limited resources for assessing the impact of an indirect source on ambient CO be directed toward those sources most likely to threaten NAAQS. Furthermore, where a threat to the CO standards is not likely, it is desirable to conduct the indirect source review for CO as expeditiously as possible so as to minimize costs of review and delay to the applicant. For these reasons, a conservative screening procedure is presented in these guidelines. When no problem in meeting the standards is found using this procedure, it may be used as a basis for granting permission to construct. If a potential problem is identified, the option for doing a more complete analysis should be presented to the applicant.

Monitoring observations in the vicinity of indirect sources have indicated that the highest concentrations of CO occur in the vicinity of access roads, at nearby intersection approaches or near entrance/exit gates.[18-21] Therefore, the CO impact analysis for indirect sources focuses on relationships between air quality and traffic design and operating parameters on access roads, at nearby intersection approaches and at exit/entrance gates. There are three key traffic determinants of emission levels on portions of roadways and/or traffic lanes which are not near intersections. These are:

1. Volume demand;
2. Volume demand to capacity ratio;
3. The type of the roadway being examined.

Volume demand is important, because it provides an estimate of the source's impact on traffic demand on access roads. When there is little congestion, volume demand is the most important traffic indicator of emissions. Volume demand to capacity ratio (v/c) is crucial, because it provides an indicator of congestion. Highly congested traffic conditions result in increased vehicle running times and lower operating speeds (resulting in closer spacing between vehicles). The spacing between vehicles which is required to service a given volume demand is, in turn, a prime indicator of emission intensity generated by vehicles using each traffic lane. Frequently, it may be difficult to project or measure traffic volume demand for each traffic lane. If it is not possible to obtain estimates of traffic volume demand (and therefore, volume demand-capacity ratios) by lane, estimates of through traffic volume demand in each direction would have to suffice. Unless there were indications to the contrary, through traffic in each direction would then be apportioned equally among the through lanes in each direction. Empirical relationships[22] between volume to capacity ratio and operating speeds, under free-flow conditions, depend on the functional type of the roadway and average highway speed or the posted speed limit, whichever is less.

The following traffic parameters are key determinants of emissions at signalized intersections:

1. Volume demand;
2. Green time to signal cycle ratio;
3. Signal cycle length;
4. Unimpeded intersection approach capacity.

Green time to signal cycle ratio (G/Cy) is the key determinant of the capacity of an intersection approach to accommodate traffic volume demand. The average length of queues forming at the intersection is directly proportional to the proportion of time that a signal cycle is not green, (i.e., (1-G/Cy)). Signal cycle length is also a determinant of queuing at an intersection approach. The shorter the signal cycle length, the shorter the average queue length occurring at the intersection approach when the light is red. However, the shorter the cycle length, the more frequently queuing is likely to occur at an intersection approach. Thus, the impact of signal cycle length on ambient CO concentrations at a selected receptor depends on the proximity of the receptor site of interest to the intersection being reviewed. Unimpeded intersection approach capacity is the amount of traffic which could be accommodated by the approach per hour of green time. This is always greater than the actual approach capacity. Unimpeded intersection approach capacity is needed to estimate green time to signal cycle ratios for each intersection approach when the signal is a traffic-actuated one. Methods of estimating unimpeded capacity and its use in the estimation of green time to signal cycle ratios are illustrated in Appendix A. Suffice it to say at this point that if the reviewer wants to use a proper G/Cy ratio in estimating the impact of traffic on ambient CO concentrations in the vicinity of an intersection with a traffic-actuated signal, unimpeded intersection approach capacity must be known for each approach and the procedure outlined in Appendix A may be followed to estimate appropriate G/Cy. The alternative is to use the more conservative assumptions about G/Cy to be described in the screening procedure.

Finally, at unsignalized intersections or at tollbooths, such as those found at exits to municipal or airport parking lots, the two key determinants of emissions are:

1. Volume demand, and
2. Volume demand to capacity ratio.

3.0 DEFINITIONS

The following definitions apply to the identified key determinants of emissions and in the derivation of the screening procedure for relating traffic on roadways and at intersections to nearby ambient CO concentrations.

Volume Demand--the average number of vehicles wanting to pass a given point in each lane during a 1-hour or 8-hour period. This parameter is expressed in vehicles per hour (vph) unless otherwise stated. For an 8-hour period, volume demand is expressed in vehicles per hour by obtaining the average hourly demand during the peak 8-hour period of interest. The terms volume demand and demand are used synonymously throughout the indirect source review guidelines.

Design Speed-- a speed selected for purposes of design and correlation of those features of a roadway such as curvature, superelevation, sight distance and type of access upon which the safe operation of vehicles is dependent.

Average Highway Speed--the weighted average of the design speeds within a highway section, when each subsection within the section is considered to have an individual design speed.

Posted Speed Limit--maximum lawful operating speed allowable for vehicles utilizing the traffic lanes of interest.

Capacity--the maximum possible number of vehicles which has a reasonable expectation of passing a given point in each lane during a given time period under prevailing roadway and traffic conditions consistent with the definition of Level of Service E. Capacity on a major urban street could typically vary from 550-1200 vph/lane assuming that intersection approach capacities provided the limiting factor on the street's capacity. On urban expressways and freeways capacity may typically vary from 1300-2000 vph/lane, assuming the terrain is reasonably level. Estimated capacities not within these ranges are not necessarily incorrect if unusual conditions regarding grade, truck or bus use, lane width, lateral clearance and/or signalization prevail.

Level of Service--a qualitative measure of the effect of a number of factors including speed and travel time, traffic interruptions, freedom to maneuver, safety, driving comfort and convenience and operating costs. For traffic which is not in the immediate vicinity of intersections, level of service is defined by the type of road, operating speed and volume-capacity ratio. At Level of Service E, volume demand to capacity ratios often exceed 0.8 and can approach 1.0. Traffic flow is unstable and there can be stoppages of momentary duration. The ranges of operating speeds and volume to capacity ratios corresponding to various designated levels of service depend on the type of the roadway to which the designation is being applied.

At signalized intersection approaches, levels of service are defined by load factors. A load factor is the ratio of the total number of green traffic signal intervals that are fully utilized by traffic during the peak hour to the total number of green intervals during that same period. The following relationships exist between levels of service at intersection approaches and Load Factors.[22]

Load Factor	Level of Service	Description
0	A	Free Flow
≤ 0.1	B	Stable Flow
≤ 0.3	C	Stable Flow
≤ 0.7	D	Approaching Unstable Flow
≤ 1.00	E	Unstable Flow

Peak Hour Factor--A ratio of the volume demand occurring during the peak hour to the maximum rate of flow during a given time period (e.g., 5 min.) within the peak hour, expanded to a full hour.

Operating Speed--Highest speed at which a driver can travel on a roadway under favorable weather conditions and under prevailing traffic conditions without exceeding safe speed as determined by average highway speed and/or posted speed limits.

Types of Roadways--Under conditions which are consistent with the maximum level of service possible for the prevailing volume-capacity ratio and vehicle operating speed, empirical relationships between volume-capacity ratio and vehicle operating speeds have been developed for certain types of roadways.[22] These roadways include:

(a) Expressways--a divided arterial for through traffic with full or partial control of access and generally with grade separations at major intersections.

(b) Freeways--an expressway with full control of access.

(c) Major street--an arterial highway with intersections at grade and direct access to abutting property, and on which geometric design and traffic control measures are used to expedite the safe movement of through traffic.

Three other types of roadways may frequently be of interest in the review of an indirect source. These are:

(d) Downtown streets--these are different from the category of "major streets," described above, in that they carry a substantial portion of circulatory rather than through traffic; heavy pedestrian traffic may increase the restrictiveness of intersections on through capacity and intersections are likely to be more closely spaced. Because the characteristics of each intersection exert such a dominant influence on traffic in each upstream segment of a downtown street, it is suggested that the analysis of an indirect source's impact on traffic and air quality at a downtown street be directed at appropriate signalized intersections.

(e) Local street--a street primarily for access to residence, business or other abutting property. It is suggested that such analysis as may be required in the vicinity of such streets be directed at the signalized or unsignalized intersections, as appropriate.

(f) Traffic lanes within indirect sources other than highways.

Vehicle Spacing--Average tailpipe-to-tailpipe distance between vehicles needed to accommodate a given volume demand at a given operating speed.

Emission Factor--Amount of CO emitted by a single vehicle per unit of time.

Distance--Unless there is specific reference to the contrary, distance refers to the perpendicular distance between a receptor and the nearest edge of a traffic lane.

Phase--A term used at signalized intersections to denote the instructions given to traffic at each intersection approach at any specified time. There are usually at least three phases at an intersection--red, green and amber. At intersections where there are turn signals or where identical phases do not occur for vehicles traveling in opposite directions (e.g. "delayed green") the number of phases is greater than three.

Cycle Length--The amount of time required for all phases of a traffic signal to occur once. Cycle lengths at fixed-time signals usually vary between 60-120 seconds. The range at traffic actuated signals is considerably larger, usually varying from 60-180 seconds.

Unimpeded Capacity--The maximum number of vehicles that could be accommodated by a signalized intersection approach if the signal were always green for that approach. For each traffic lane, this parameter is expressed in vehicles per hour of green time, and is always greater than the actual intersection approach capacity per lane. Typical values may range from 1100-1700 vehicles/lane/hr. of green time.

Green Time to Signal Cycle Ratio--The fraction of the time that a traffic light is green at a specified intersection approach.

Upstream--Traffic which has not yet passed a specified location (e.g., an intersection) is said to be upstream from that location. Traffic already having passed by the location is downstream traffic.

Intersection Leg--On a 4-way intersection (for example) each of the roads leading to and from the intersection is called a leg to that intersection. An intersection approach is that portion of an intersection leg which is upstream from the intersection.

Operation Modes--A description of the manner in which a vehicle is being operated. Generally there are four modes of operation: acceleration, deceleration, cruising and idling. Modal emissions refer to emission factors for CO which are appropriate for each distinctive mode of operation.

Cold Start--If a vehicle has not been run for a period of time (i.e., cold soak period), when it is restarted and for a short period thereafter, it runs less efficiently than it does after the engine has warmed up. This lower engine efficiency results in higher emissions of CO. At indirect sources where vehicles are likely to sit for substantial periods of time, the cold start problem may significantly affect CO emissions in the vicinity of a source. The extent of the impact of cold starting vehicles depends on a number of factors including length of the cold soak period, ambient temperature and engine size.

Receptor Site--A location where it is of interest to estimate ambient CO concentrations. In general terms, analysis should center on reasonable locations in the vicinity of that portion of the traffic network (e.g., parking lot, access roads, intersections) where the combined impact of the proposed source and other traffic is likely to result in the highest traffic demand and/or most traffic congestion. Definition of "reasonable" depends on the legal interpretation of the word "ambient." "Ambient" is interpreted as meaning that portion of the atmosphere, external to buildings, to which the general public has access.[23] The primary standards for CO imply that reasonable sites are required to be in locations to which the general public (note: not necessarily any specific individual) has access. The recommended procedure for selecting such sites is through joint review by the reviewing agency and applicant of maps and plans of the area and facility which are required as part of the indirect source or parking management application. To clarify what might generally be regarded as reasonable or unreasonable receptor sites, a few examples are cited below. It should be strongly emphasized that these examples only suggest what is generally expected to be the case. If the review of a specific application reveals that a site which may ordinarily be unreasonable is, in fact, reasonable in a specific case (or vice versa) then, of course, the specific ruling would supersede this general guidance.

a. Examples of Reasonable Receptor Sites

(1) All sidewalks where the general public has access on a more or less continuous basis are reasonable receptor sites;

(2) A vacant lot in which a neighboring facility is planned and in whose vicinity the general public (including employees if the neighboring facility is not being built for the prime purpose of traffic control) would have access continuously is a reasonable receptor site;

(3) Portions of a parking lot to which pedestrians have access continuously are reasonable receptor sites;

(4) The vicinity of parking lot's entrances and exits is a reasonable receptor site, providing there is an area nearby, such as a public sidewalk, residences or structures (e.g. an auto service center at a shopping center) where the general public is likely to have continuous access;

(5) The property lines of all residences, hospitals, rest homes, schools, playgrounds, and the entrances and air intakes to all other buildings are reasonable receptor sites.

b. Examples of Unreasonable Receptor Sites

(1) Median strips on roadways;
(2) Locations within the right-of-way on limited access highways;
(3) Within intersections or on crosswalks at intersections;
(4) Tunnel approaches;
(5) Within tollbooths;
(6) Portions of parking lots where the general public is not likely to have access continuously.

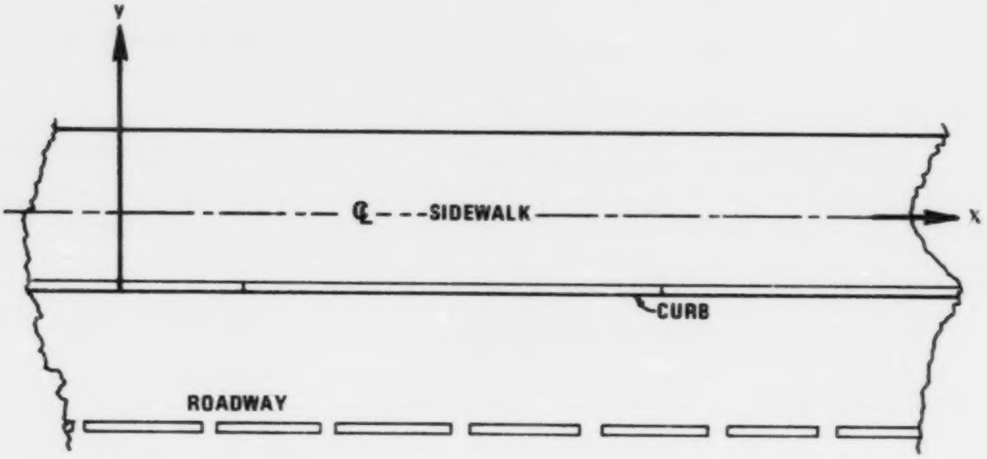
One further aspect of the "reasonable receptor site" problem remains to be discussed. That is, where within a sidewalk, occupied lot, vacant lot, etc. should the receptor site be assumed. Generally, reasonable receptor sites would be located as follows:

(1) Occupied lot--nearest edge of the subarea within the lot where the general public has continuous access. If this cannot be determined, use the lot's property line which is nearest to the traffic lanes being reviewed.

(2) Vacant lot--same as occupied lot.

(3) Sidewalks--sidewalks present a problem in that the general public is unlikely to occupy a relatively small portion of the walkway continuously. Nevertheless, the general public does have access to the sidewalk as a whole on a continuous basis. This suggests that it is appropriate to consider the sidewalk as a whole as a reasonable receptor

site. This further implies that one should estimate representative CO concentrations prevailing at nose height over the sidewalk during the worst 1- and 8-hour periods. The sketch shown below illustrates a sidewalk in which the Y direction is the direction perpendicular to curbside and the X direction is the direction parallel to the curb.



Since the diminution of CO concentration with distance from the curb is approximately linear over distances which sidewalks are generally found from roadways (see Figures 5, 8 and 10 in Section 4.1), it should generally be sufficient to choose the sidewalk's centerline as the location at which to estimate CO concentrations. In order to estimate representative concentrations at the sidewalk, it is also necessary to average estimated concentrations along the sidewalk's centerline (i.e., in the "X" direction). In general, this longitudinal averaging would be done for each block (i.e., including 2 intersections and a mid-block section). This cannot be a hard and fast rule, however, since it depends on a walkway's configuration. For example, a walkway from a facility to a parking lot may not traverse what is ordinarily thought of as a block. The longitudinal averaging procedure is further described in Section 4.1.4 and illustrated by Example 11 in Section 4.6.

4.0 SCREENING PROCEDURE FOR REVIEWING THE IMPACT OF A PROPOSED INDIRECT SOURCE ON AMBIENT CONCENTRATIONS OF CO

Ambient concentrations of carbon monoxide may be regarded as the sum of two components:

(1) Concentrations attributable to traffic in the immediate vicinity of the receptor site, and

(2) Background concentrations attributable to more remote sources of CO which may or may not be related to the operation of the proposed source.

The screening procedure assumes, on the basis of several monitoring studies conducted for EPA,[18-21] that the greatest potential threat to ambient air quality standards for CO occurs at locations where the first component is relatively important. Consequently, the screening technique focuses on three such locations:

(1) The vicinity of traffic lanes accommodating freely flowing traffic;

(2) The vicinity of signalized intersections;

(3) The vicinity of non-signalized intersections or tollbooths. These locations are illustrated for a hypothetical parking lot in Figure 1. The screening procedure is developed in the following manner. First, curves for estimating the impact of nearby traffic on ambient concentrations of CO over 1-hour sampling times are presented for each of the three types of locations depicted in Figure 1. Second, procedures for estimating the impact of this traffic on 8-hour ambient CO concentrations are described. Next, manners of estimating the background component of the ambient concentration are presented.

Fourth, consideration of vehicle operating factors such as fraction of cold starts, and applicability of Federal emission standards is discussed. Fifth, a calculative procedure appropriate for estimating the impact of event-oriented sources is presented. Sixth, examples using Figure 1, the various curves, and techniques developed in the first five sections are presented to better illustrate the screening procedure. Finally, the screening procedure is summarized.

4.1 Impact of Traffic on Nearby 1-hour CO Concentrations

4.1.1 Freely Flowing Traffic

There are four types of roadways near which the impact of freely flowing traffic on nearby ambient CO concentrations may be of interest. These are freeways, expressways, midblock sections of major streets and traffic lanes within indirect sources other than highways. Figures 2, 3 and 4 estimate the impact of traffic volume demand, capacity and demand-capacity ratio on ambient CO concentrations averaged over a 1-hour sampling time at a receptor located a perpendicular distance of 10 meters from the edge of a traffic lane. Identification of a lane's traffic capacity and demand-capacity ratio defines the lane's traffic volume demand as well. For example, in Figure 2, if the lane capacity is 2000 vph and the demand-capacity ratio is 0.6, the volume demand is 1200 vph and the resulting impact of traffic in the lane on 1-hour CO concentrations of a receptor located a perpendicular distance of 10 meters away is 3.8 ppm. Figure 5 depicts the relationship between the maximum impact of a traffic lane on ambient CO concentrations and the perpendicular distance between a traffic lane and the selected receptor site. By using Figure 5 and the appropriate one of Figures 2-4, it is possible to estimate the maximum impact of a roadway with any specified number of lanes having any specified width. This procedure is illustrated in Example 1 in Section 4.6.

4.1.2 Traffic at Signalized Intersections

Figures 6, 7 and 8 are used in the screening procedure to estimate the impact of traffic at signalized intersections. Figure 6 is used to determine the maximum impact of traffic in a lane upstream from the signal on ambient CO concentrations at a receptor site 10 meters away. The impact depicted in Figure 6 arises from the traffic cruising by the intersection approach during the green phase of the signal, accelerating and decelerating traffic when the light is red or shortly after it turns to green, and idling traffic occurring during the red phase of the signal. It is apparent from Figure 6 that the green time to signal cycle ratio (G/Cy) exerts an important influence on nearby ambient CO levels. This ratio is a constant at fixed-time signals and should be readily obtainable. At traffic actuated signals however, G/Cy depends not only on the traffic demand for the intersection approach to which the screening technique is being applied, but upon the demand at all the other approaches as well. A method for estimating green time to signal cycle ratios at traffic actuated signals is presented in Appendix A. For purposes of the screening procedure, however, unless there is specific information to the contrary, a G/Cy of 0.6 should be assumed for the approach having the highest demand on a major street. A green time to signal cycle ratio of 0.5 is probably more appropriate for approaches on local streets or for exits leading from indirect source parking lots. The rationale for these assumptions is presented in Section 6.3. Note that it would be possible to simulate the maximum impact of a left-hand turn lane with a left-hand signal by assuming a low G/Cy ratio (e.g., 0.2) prevails for the left signal. The demand used in such a procedure would be the number of vehicles wanting to turn left.

In analyzing the maximum impact of a leg to an intersection, it is also necessary to estimate the effect of traffic on the leg, moving in the opposite direction, which is downstream from (i.e., has already passed) the signal. Figure 7 is used for this purpose. The curve which should be used on Figure 7 is determined by the vehicle operating speed at midblock. Table 4 in Section 6.3 provides an indicator of how operating speed may vary with volume to capacity ratios on major streets. If it is not feasible to determine volume-capacity ratio at midblock, use a speed of 15 mph for city streets and indirect sources, and 30 mph for major streets.

Figure 8 depicts the sensitivity of the impacts estimated with Figures 6 and 7 to the perpendicular distance between a selected receptor site and a traffic lane. Note that the "upstream curve" in Figure 8 denotes a more rapid decrease of concentration with distance than the "downstream curve" does. This is a result of the impact of idling and accelerating/decelerating vehicles exhibited over a finite portion of roadway being more sensitive to distance than is freely flowing traffic over a long stretch of road. Figure 8 may be used in conjunction with Figures 6 and 7 to estimate the maximum impact, at any distance, of traffic on a leg of a signalized intersection having any designated number of lanes of any width. The use of Figures 6-8 to perform such an analysis is illustrated in Example 2 in Section 4.6.

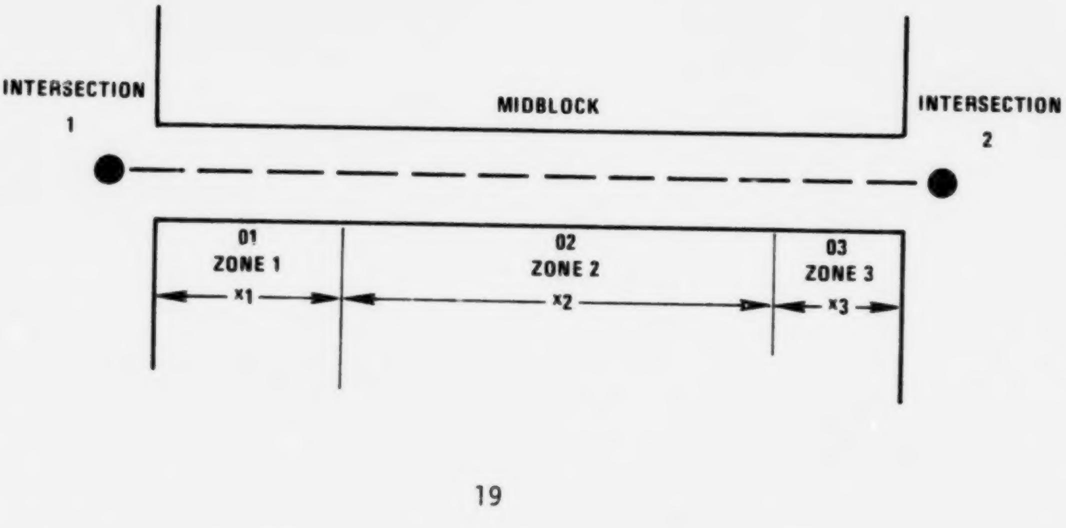
4.1.3 Traffic at Tollbooths and Unsignalized Intersections

Figures 9, 7 and 10 are used in the screening procedure to estimate the impact of traffic at non-signalized intersections and in the vicinity of tollbooths. Figure 9 identifies relationships between volume demand, capacity and volume demand-capacity ratio and the impact of traffic in a lane upstream from a non-signalized intersection or tollbooth on CO concentrations at a distance of 10 meters from the edge of the lane. Figure 9 compares the impacts of two operating conditions in such a lane. At low demand-capacity ratios, congestion is minimized and the problem posed by queues of vehicles forming at unsignalized exits/entrances to an indirect source or at unsignalized intersections is minimal. Under such circumstances, the impact on CO concentrations at nearby receptors is directly proportional to volume demand passing the receptor. As the demand-capacity ratio increases, queue formation is likely to exert an increasingly important impact on nearby ambient CO concentrations. The solid "free-flow curves" in Figure 9 depict the range of volume demand-capacity ratios for which the volume demand per se may exert the most important influence on nearby ambient CO concentrations. For demand-capacity ratios exceeding the ratio at which the appropriate free-flow curve intersects the queuing curve, queuing at an intersection or exit/entrance may exert the maximum impact on nearby ambient CO concentrations, and the queuing curve should be used to estimate the impact at nearby receptors.

Figure 7 is used to estimate the impact of traffic in the opposite direction which is downstream from the intersection or tollbooth under review. Figure 10, when combined with Figures 9 and 7, enables the reviewer to estimate the impact of any number of lanes of any width at a receptor site located up to 100 meters away. This procedure is illustrated in Example 3 in Section 4.6.

4.1.4 Estimating Representative Concentrations on Sidewalks

The suggested screening procedure for estimating representative concentrations on sidewalks is to estimate the average concentration along the sidewalk's centerline at breathing height. Where feasible, average concentrations should be determined for each sidewalk on each block which is of interest. Average concentrations along the sidewalk's centerline can be estimated by determining concentrations along a sidewalk's centerline for each zone of the sidewalk using guidance in Sections 4.1.1-4.1.3 as appropriate. For a typical block, there would be three zones (2 intersections, 1 midblock) as shown in the sketch below.



For the case pictured in the sketch, the representative concentration along the sidewalk centerline would be determined using the following expression.

$$(\text{conc})_{\text{rep}} = \frac{(\text{conc})_1 \, (X_1) + (\text{conc})_2 \, (X_2) + (\text{conc})_3 \, (X_3)}{(X_1 + X_2 + X_3)}$$

The size of the respective zones (i.e., X_1, X_2 and X_3) would be determined using Equations (7) and (8) in Section 6.1 to determine the size of zones dominated by signalized and non-signalized intersections respectively. The remaining portion of the block would be assumed to be dominated by midblock traffic conditions. This procedure is illustrated with Example 11 in Section 4.6.

4.2 Impact of Traffic on Nearby 8-hour CO Concentrations

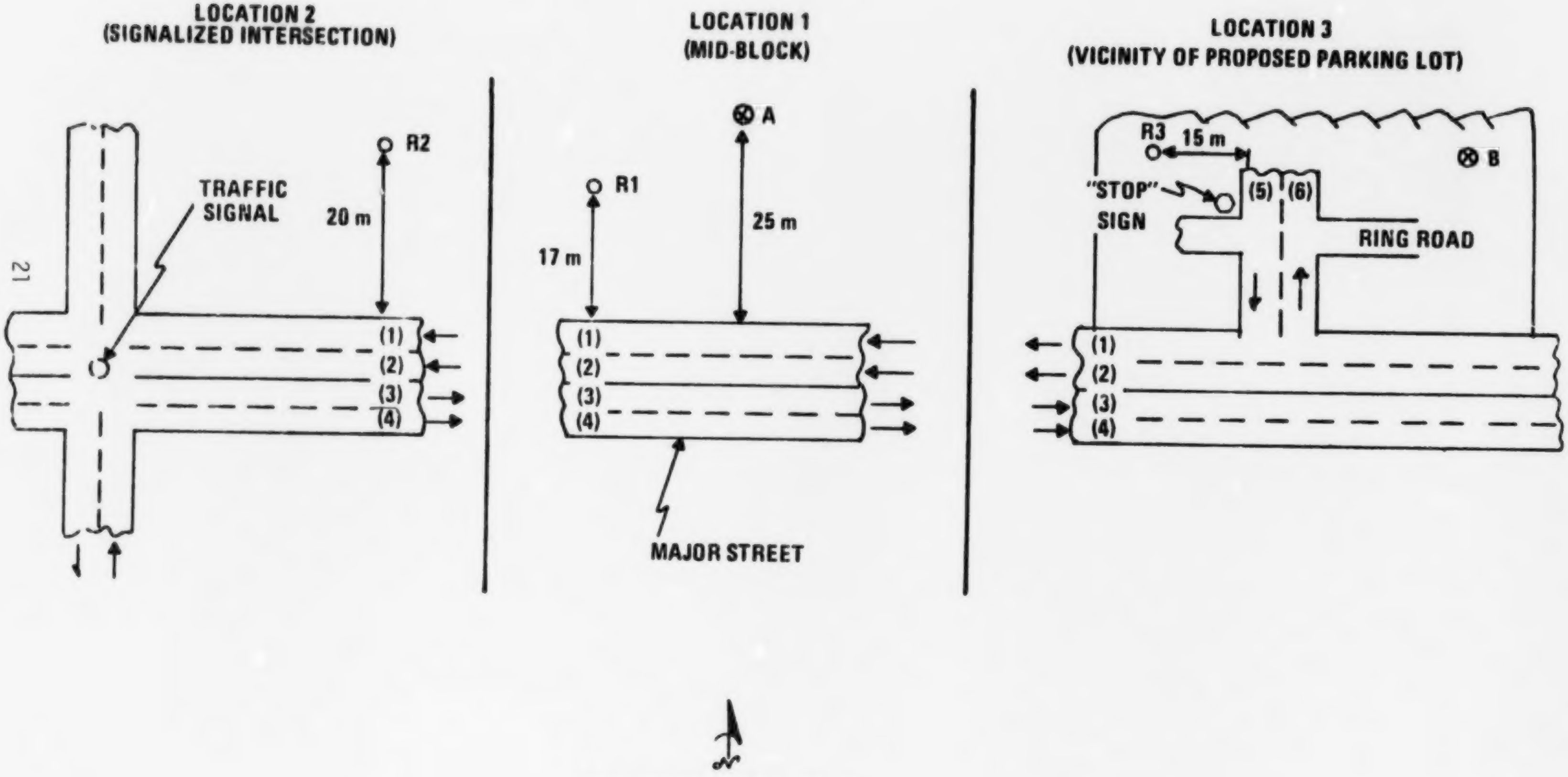
Two adjustments must be made to the procedures described in Section 4.1 in order to adapt the screening procedure for estimating the impact of traffic on nearby 8-hour concentrations of CO.

1. Volume demand appropriate for the peak 8-hour use period must be used. This demand would be obtained by estimating the mean hourly volume demand during the 8-hour period of interest. In all cases the peak 8-hour volume demand would be less than the peak 1-hour volume demand.

2. Account must be taken of the lack of persistence of the unfavorable meteorological conditions which were assumed in deriving Figures 2-10. The following procedure is suggested for deriving a persistence factor to account for meteorological variations occurring over an 8-hour sampling period.

Figure 1

KEY LOCATIONS IN THE REVIEW OF A HYPOTHETICAL INDIRECT SOURCE


LOCATION 2
(SIGNALIZED INTERSECTION)
TRAFFIC SIGNAL
R2
20 m
(1)
(2)
(3)
(4)
LOCATION 1
(MID-BLOCK)
A
R1
17 m
25 m
(1)
(2)
(3)
(4)
MAJOR STREET
LOCATION 3
(VICINITY OF PROPOSED PARKING LOT)
R3
15 m
B
"STOP" SIGN
(5)
(6)
RING ROAD
(1)
(2)
(3)
(4)
N

(DRAWINGS NOT TO SCALE)

Figure 2

VOLUME DEMAND - CAPACITY RATIO IN A FREEWAY OR EXPRESSWAY LANE VERSUS CO CONCENTRATION IMPACT AT A PERPENDICULAR DISTANCE OF 10 METERS

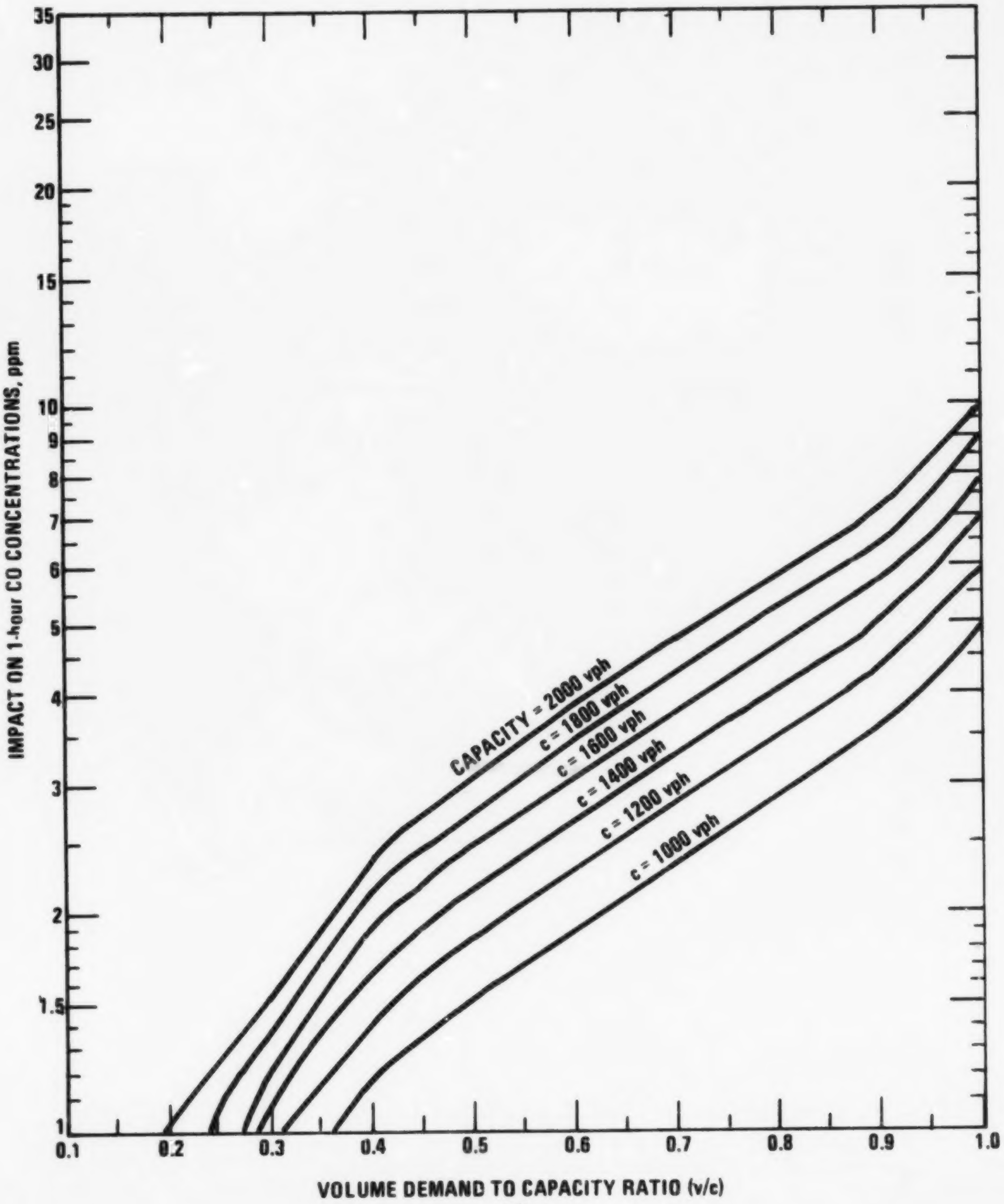


Figure 3

VOLUME DEMAND - CAPACITY RATIO IN A LANE ON A MAJOR STREET VERSUS CO CONCENTRATION IMPACT AT A PERPENDICULAR DISTANCE OF 10 METERS

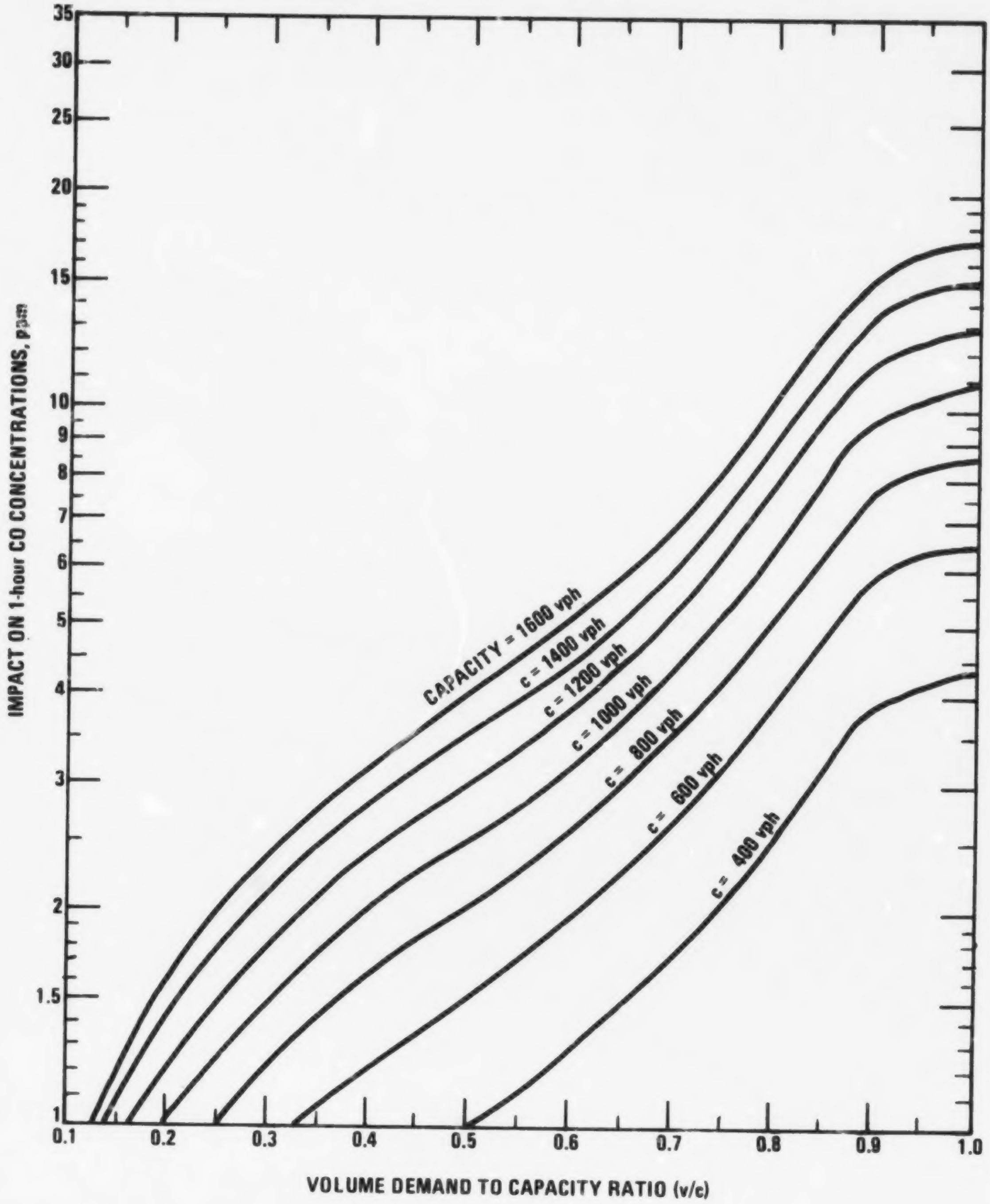


Figure 4

VOLUME DEMAND - CAPACITY RATIO IN A LANE WITHIN AN INDIRECT SOURCE VERSUS CO CONCENTRATION IMPACT AT A PERPENDICULAR DISTANCE OF 10 METERS

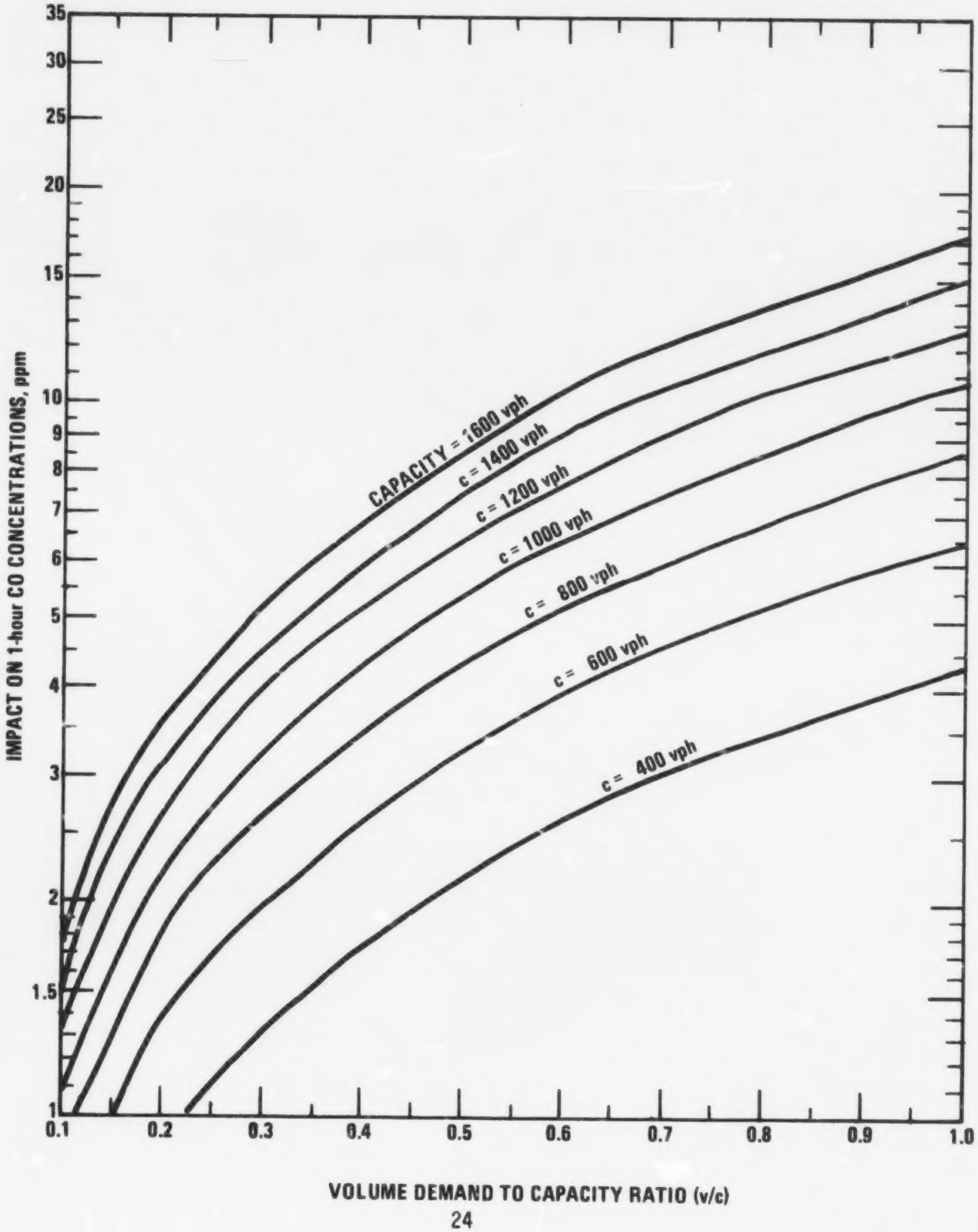


FIGURE 5. RELATIVE CONCENTRATION OF CO VS. PERPENDICULAR DISTANCE FROM A TRAFFIC LANE WITH FREELY FLOWING TRAFFIC

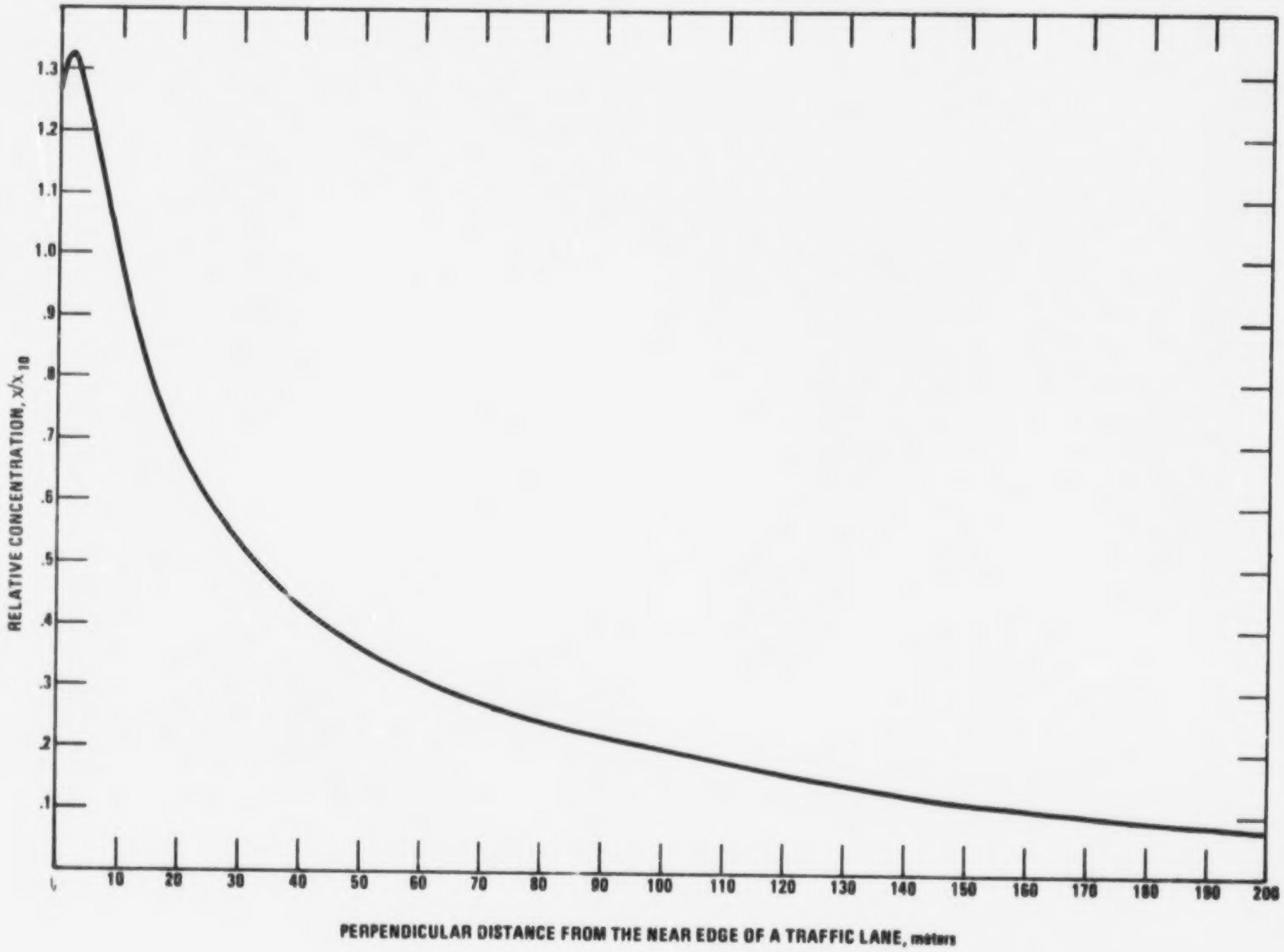


Figure 6

MAXIMUM IMPACT OF TRAFFIC IN AN APPROACH LANE UPSTREAM FROM A SIGNALIZED INTERSECTION AT A RECEPTOR SITE LOCATED AT A PERPENDICULAR DISTANCE OF 10 METERS

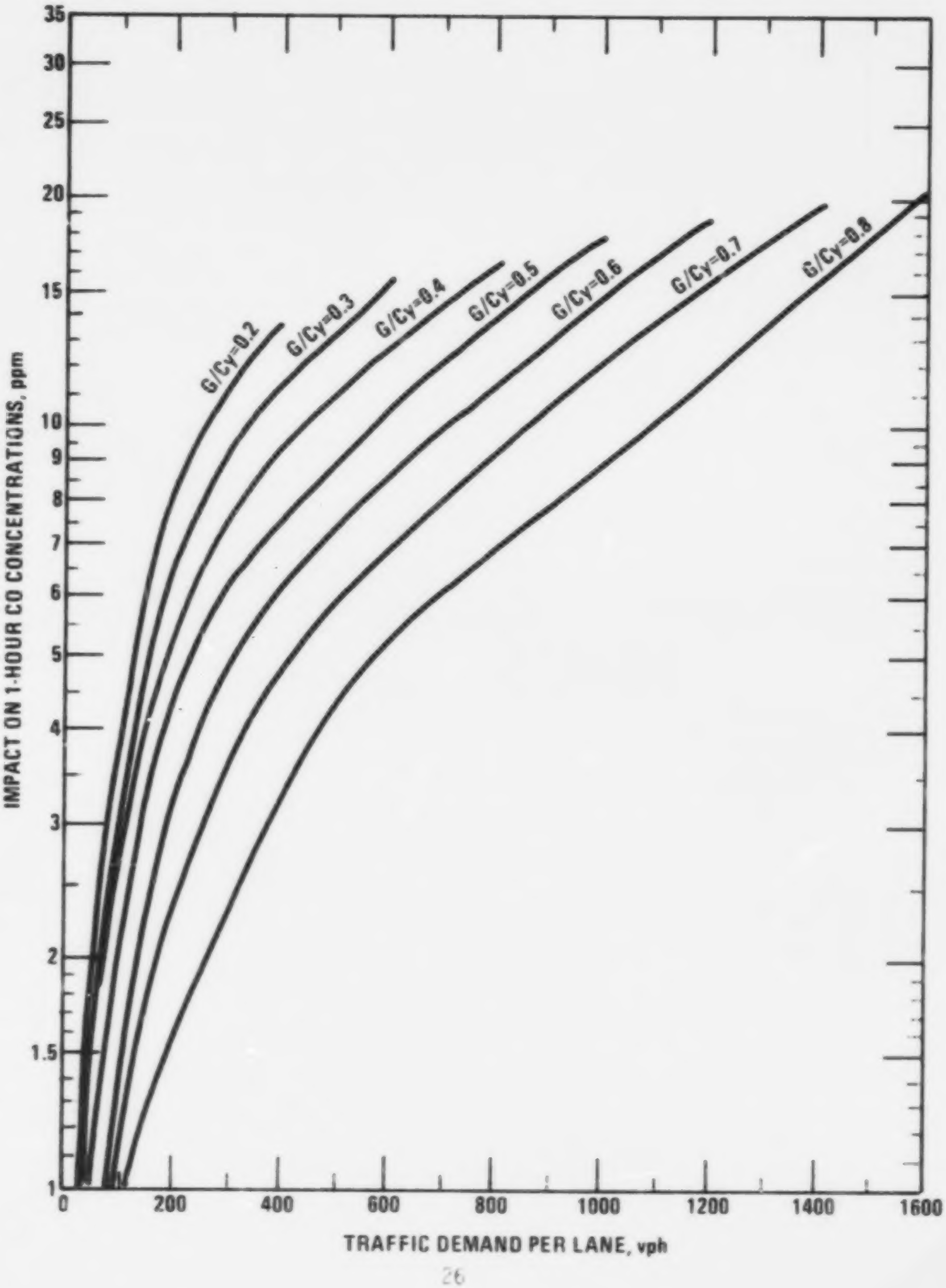


Figure 7

MAXIMUM IMPACT OF TRAFFIC IN A LANE DOWNSTREAM FROM AN INTERSECTION AT A RECEPTOR SITE LOCATED A PERPENDICULAR DISTANCE OF 10 METERS AWAY

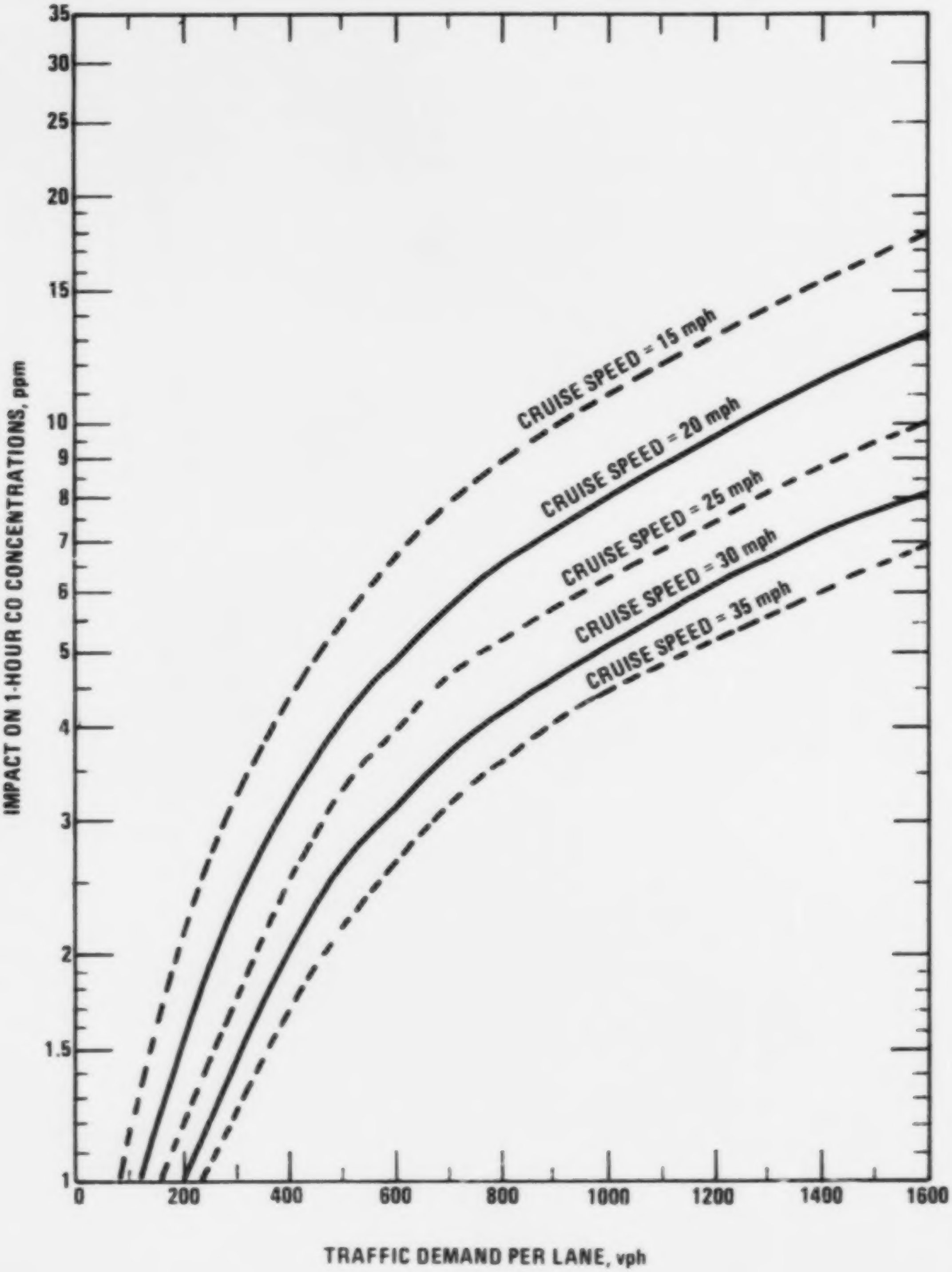


FIGURE 8. RELATIVE CONCENTRATION OF CO VS. PERPENDICULAR DISTANCE FROM A TRAFFIC LANE NEAR A SIGNALIZED INTERSECTION

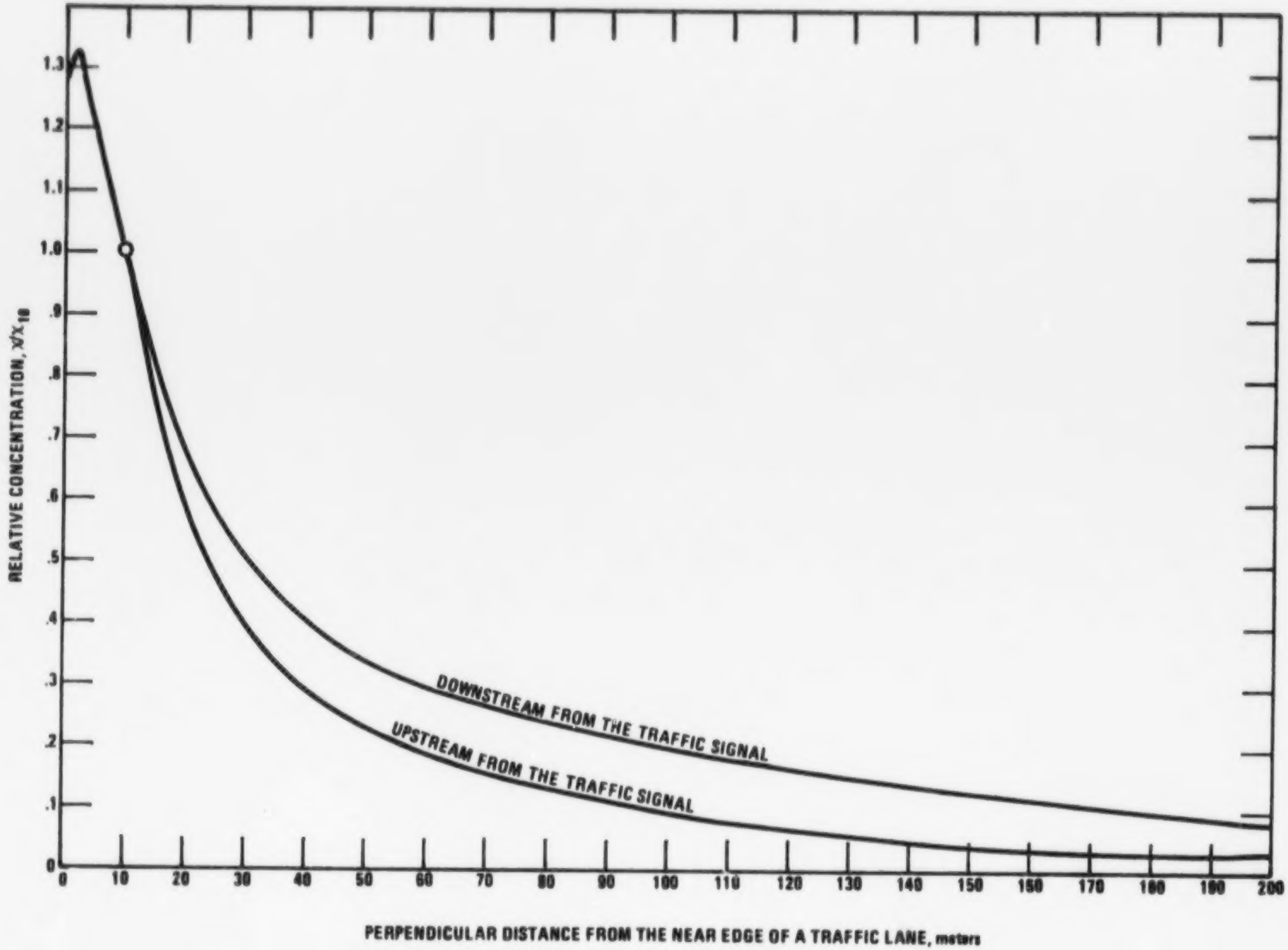


Figure 9

IMPACT OF TRAFFIC UPSTREAM FROM A NON-SIGNALIZED INTERSECTION ON CO CONCENTRATIONS AT A RECEPTOR SITE LOCATED A PERPENDICULAR DISTANCE OF 10 METERS AWAY

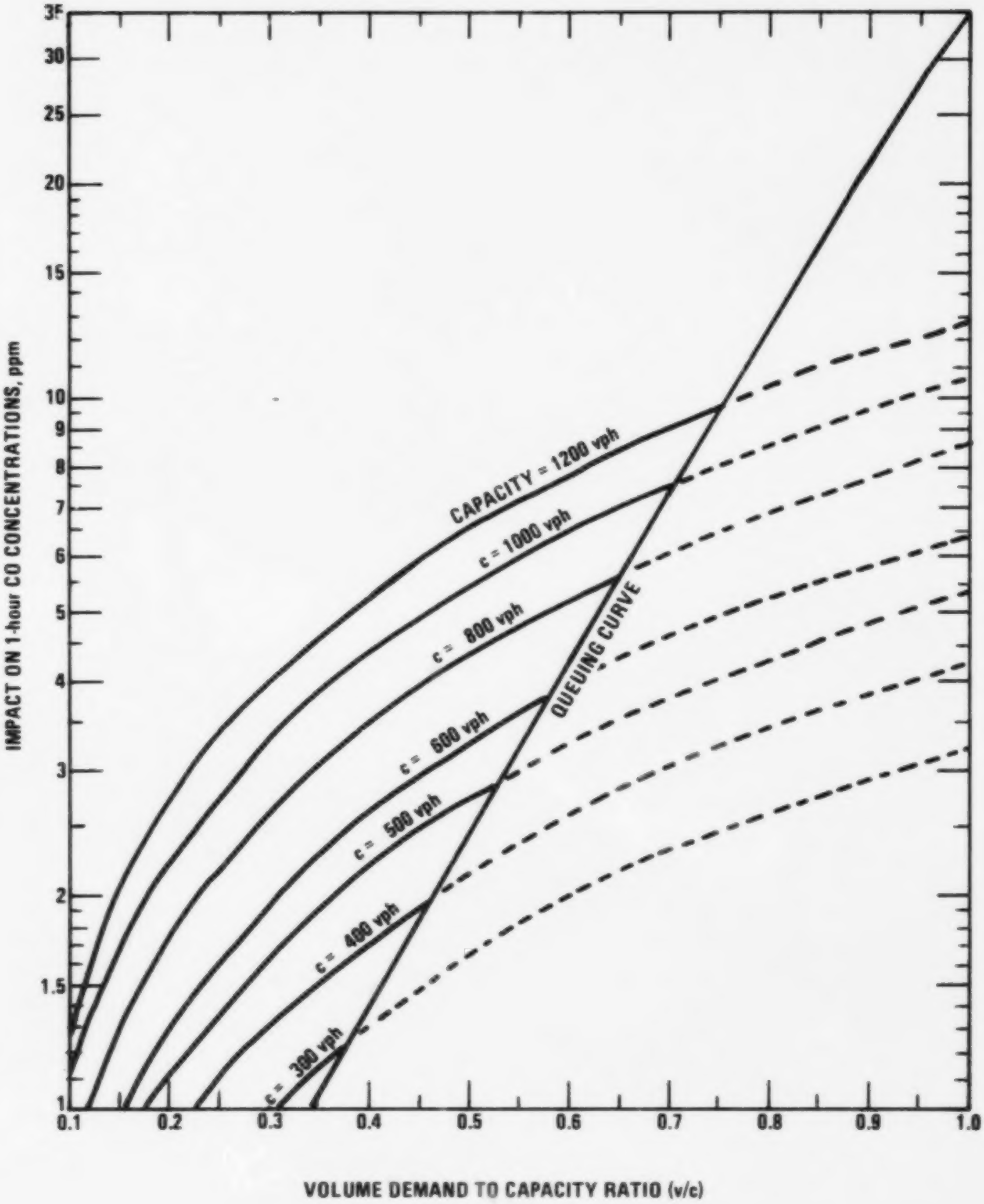
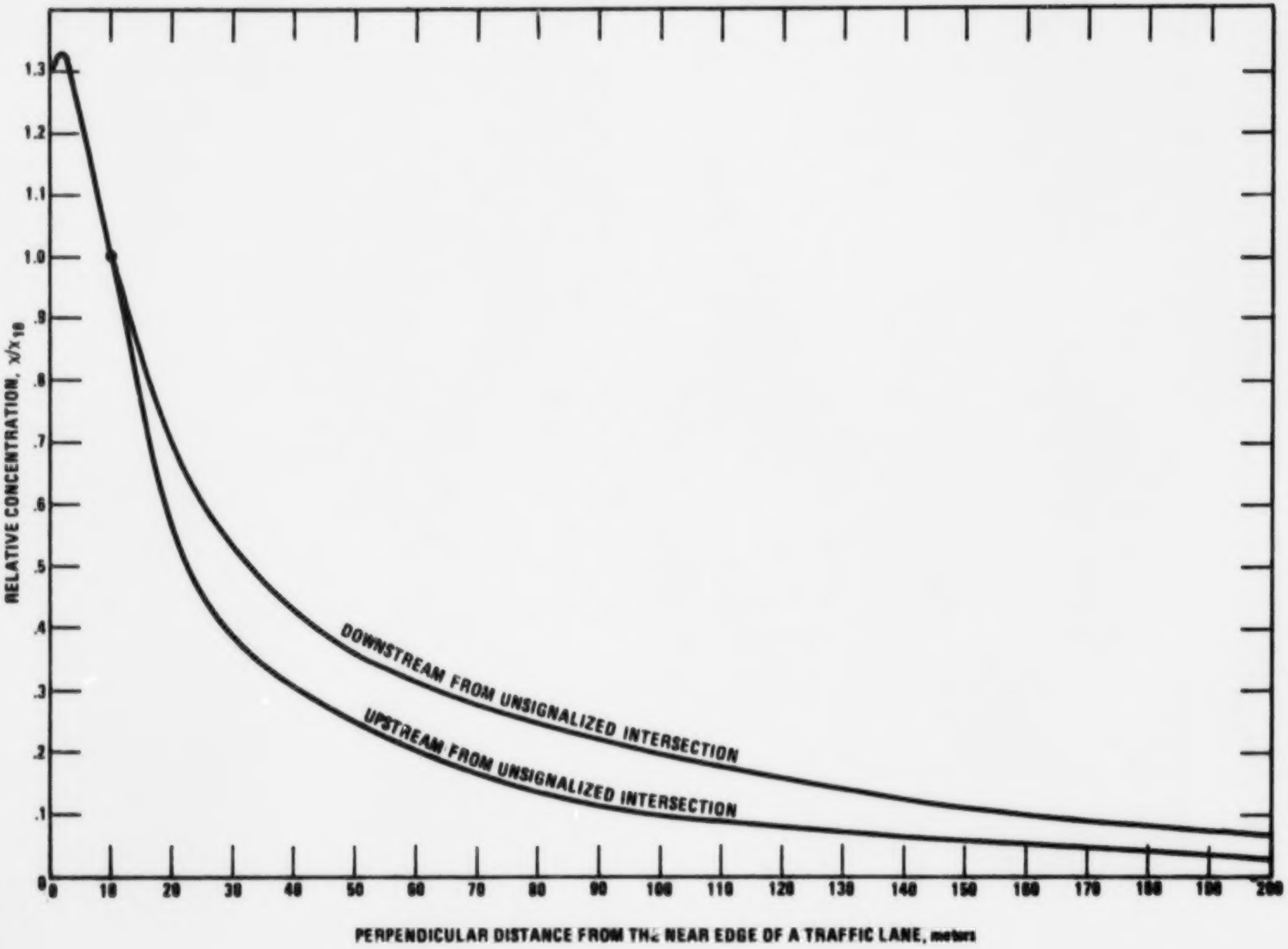


FIGURE 10. RELATIVE CONCENTRATION OF CO VS. PERPENDICULAR DISTANCE FROM A TRAFFIC LANE NEAR AN UNSIGNALIZED INTERSECTION



(a) Select an existing indirect source or roadway configuration similar to ones which are likely to be proposed and which is located in an area where wind variability is likely to be representative (e.g., an existing source located in a street canyon, where channeling may occur would not be suitable unless a proposed source were also to be located in such a site).

(b) Monitor hourly traffic at the main gate for the selected existing source or on the existing roadway, wind speed and direction at the site and ambient CO concentrations within 50 m of the selected gate or roadway.

(c) For each day, note the highest measured 1-hour CO concentration occurring with wind speeds less than 2 m/sec. Note the traffic demand measured in both directions at the gate or on the road during this period.

(d) For each day, note the highest 8-hour running average CO concentration at the existing source during hours of operation, along with the average hourly traffic volume occurring in both directions at the selected gate during this period. If a roadway is selected, follow the same procedure, but limit observations to those times of day in which the proposed source will be operating.

(e) For each day, the persistence factor, p, can be estimated using Equation (1).

$$p = \left[\frac{\text{(Max. 8-hour average concentration)}}{\text{(Max. 1-hour concentration with wind speed} < 2\text{ m/sec)}}\right]\left(\frac{V_1}{V_8}\right) \qquad (1)$$

where p = 1- to 8-hour persistence factor, dimensionless

V_1 = traffic volume demand in both directions during the hour in which highest CO concentrations were observed, vph

V_8 = average hourly traffic volume demand in both directions during the 8-hour period in which the highest 8-hour running average CO concentration is observed, vph

(f) Choose the highest observed persistence factor and multiply it by the estimates obtained using Figures 2-10 to estimate the maximum 8-hour impact at the selected receptor.

Using a procedure similar to the one outlined above, a maximum persistence factor of "0.6" was observed during an EPA-sponsored monitoring study at an indirect source.[20] If it is infeasible to derive a persistence factor, or until such time as the appropriate data become available, a value of "0.6" may be assumed.

Derivation and use of a meteorological persistence factor to estimate 8-hour concentrations of CO are illustrated in Example 4 in Section 4.6.

4.3 Estimation of Background CO Concentrations

Sections 4.1 and 4.2 have discussed means whereby the impact of traffic on nearby ambient CO concentrations can be assessed. It is likely that the most severe threat to National Ambient Air Quality Standards (NAAQS) for CO will occur where this impact is great. However, merely estimating the impact of nearby traffic may not be sufficient to determine whether the standards are threatened. Even though the background concentration may frequently be very much less than the impact of nearby traffic on ambient CO concentrations, the background component should be included in order to compare estimated ambient concentrations of CO with the NAAQS. Occasionally, when a source is to be located in a rural area and there are no reasonable receptor sites at the downwind edge of the proposed parking lot, a natural background of 1 ppm may be assumed.[24] More often, however, use of natural background levels may not be sufficient. Several approaches for estimating background concentrations are described in Appendix H. The two preferable methods for estimating background levels would be:

(1) Note the second highest 1- and 8-hour CO concentrations observed, during hours in which the proposed indirect source would operate, at a continuously operated monitoring site over the past year which is situated near the site of the proposed source or at a similarly situated existing source and adjust these observations to account for the effect National emission control programs will have after the proposed source's first year of operation; or

(2) Use the results of a calibrated meso-scale diffusion model to estimate high representative 1- and 8-hour concentrations likely to occur during hours in which the proposed source would operate.

Unfortunately, frequently the necessary information may not be available to take advantage of either of these two approaches. Unless the data are already available or the modeling exercise has already been completed, both approaches require more effort than is appropriate for the indirect source screening procedure. Indeed, the indirect source regulations[1] imply that an applicant may be required to monitor ambient CO concentrations for no longer than 14 days. In cases where it is not possible to use one of the two above procedures, it may frequently be necessary for the applicant to monitor ambient CO concentrations for a limited period. The remaining portion of this section assumes that such is the case, and discusses how the collected data might be interpreted and used to estimate ambient background concentrations.

4.3.1 Seasonal Adjustment of Observed Concentrations

Since an applicant may only be required to monitor ambient CO levels for at most 14 days, there is a strong likelihood that the highest 1- and 8-hour background concentrations occurring during a source's operating hours will not be observed. To compensate for this, the observed data should be seasonally adjusted. Two possible methods for adjusting observations are described below. Other methods may be just as satisfactory or even preferable if they are more suited to the available data. The first method described requires the presence of a continuous monitoring station which has been operating somewhere within the regional area of interest for a year. The second method is less satisfactory, but does not require the presence of a historical monitoring site.

Method 1--Use of Historical Data

(1) Note the highest 1- and 8-hour CO concentrations observed at the applicant's monitoring site during the times of day in which the proposed source would be operating.

(2) Note the highest observed 1- and 8-hour concentrations during the source's operating hours at the historical site most closely corresponding to the site of the applicant's monitor during the 14 day monitoring period.

(3) Note the highest observed 1- and 8-hour concentrations at the historical site over the past year during the source's operating hours.

(4) Apply Equation (2) to estimate the seasonally adjusted background concentration.

$$x_b = \frac{\begin{pmatrix}\text{Max. observed 1-hr conc.}\\ \text{@ applicant's site}\\ \text{during source operating}\\ \text{hours}\end{pmatrix}\begin{pmatrix}\text{Max. obs. 1-hr. conc.}\\ \text{@ historical site during}\\ \text{source operating hours}\\ \text{in past year}\end{pmatrix}}{\begin{pmatrix}\text{Max. observed 1-hr. conc. @ historical}\\ \text{site during source operating hours}\\ \text{during the 14-day period}\end{pmatrix}} \tag{2}$$

(5) The seasonally adjusted 8-hour background concentration would be obtained by substituting 8-hour concentrations for 1-hour concentrations in Equation (2).

If hourly data are not readily available at the historical site, steps (2)-(3) and Equation (2) would have to be altered as follows:

(2a) Note the highest observed 1- and 8-hour concentrations at the historical site most closely corresponding to the site of the applicant's monitor during the 14 day monitoring period.

(3a) Note the highest observed 1- and 8-hour concentrations at the historical site over the past year.

(4a) Apply Equation (2a) to estimate the seasonally adjusted background concentration.

$$x_b = \frac{\begin{pmatrix}\text{Max. obs. 1-hr. conc.}\\ \text{@ applicant's site during}\\ \text{source operating hrs.}\end{pmatrix}\begin{pmatrix}\text{Max. obs. 1-hr.}\\ \text{conc. @ historical site}\\ \text{during past year}\end{pmatrix}}{\begin{pmatrix}\text{Max. obs. 1-hr. conc. @ historical}\\ \text{site during 14-day period}\end{pmatrix}} \tag{2a}$$

The use of historical data to estimate background concentrations is illustrated further by Example 5 in Section 4.6.

Method 2--Use of Pollution Potential

(1) Note highest 1- and 8-hour CO concentrations observed at the applicant's monitoring site during the times of day in which the proposed source would be operating.

(2) Note the $\bar{\chi}/\bar{Q}$ value in the appropriate part of the United States from the Figures 42-45 in AP-101^{25} which correspond to the time of year in which the monitoring is undertaken by the applicant.

(3) Note the maximum $\bar{\chi}/\bar{Q}$ value for the appropriate area of the country from Figures 42-45. Use the value for the larger city to emphasize seasonal differences.

(4) Use Equation (3) to seasonally adjust observed background concentrations.

$$\chi_b = \frac{\begin{pmatrix}\text{Max. obs. 1- or 8-hr. conc.} \\ \text{@ applicant's site during} \\ \text{source operating hours}\end{pmatrix}\begin{pmatrix}\text{Maximum } \bar{\chi}/\bar{Q} \text{ from} \\ \text{AP-101}\end{pmatrix}}{\begin{pmatrix}\bar{\chi}/\bar{Q} \text{ from AP-101 during time of year} \\ \text{in which monitoring is performed}\end{pmatrix}} \qquad (3)$$

Method 2 is illustrated further by Example 5 in Section 4.6.

4.3.2 Interpretation of Monitoring Data at Proximate and Representative Sites

A monitoring site's location may frequently be determined by practical constraints such as availability of electrical power and security. The resulting location of an ambient monitoring site affects the manner in which the screening procedure is applied. In general, there are two types of sites, representative sites and proximate sites. A proximate site is one where the monitor is within 100 meters of the traffic lanes to which the screening procedure is being applied. As such, these data may already reflect a significant contribution from the traffic lanes being evaluated. Indiscriminate application of the approaches suggested in Section 4.1 may result in the traffic lanes' impact being counted twice. Thus, it is suggested that if the only feasible sites are proximate ones, hourly traffic volumes on the nearby roadway be monitored as well. It would then be possible to "calibrate" the curves in Section 4.1 so that the estimated and observed concentrations agree for the observed level of traffic. Next, the maximum increase in traffic attributable to the new source and/or seasonal differences in other traffic using the road should be added to the observed traffic and the incremental impact should be estimated using the "calibrated" curves. The above procedure is illustrated more completely by Example 6 in Section 4.6.

The advantage of using data obtained from a proximate site is that such data may be used to help estimate 8-hour persistence factors as described in Section 4.2. There are several disadvantages, however. First, additional traffic data may be required. Second, if there are several different types of critical locations (e. g., at midblock, at signalized intersections, at non-signalized intersections), only the curves appropriate for the type of location near which the monitoring site is located may be "calibrated." Third, the computations required to use proximate data in the screening procedure are more complex. On balance it is suggested that representative sites be used to obtain air quality data whenever possible.

A representative site is one located at least 100 meters from major traffic lanes. The concentrations observed at such sites are not likely to be dominated by traffic in the lanes being evaluated with the screening procedure. The use of seasonally adjusted maximum background concentrations from representative sites is straightforward. The 1- and 8-hour background values thus obtained are simply added to the impact attributable to nearby traffic. This is illustrated in Section 4.6 with Example 7.

4.3.3 Estimating the Impact of Remote Sources within a Proposed Parking Lot

When a receptor site is located within or at the downwind edge of a proposed parking lot, the impact of emissions which may take place within the lot, but not in the immediate vicinity of the receptor site should be accounted for. This can be done in two ways. First, the monitoring site selected to estimate background concentrations could be located in the vicinity of an existing lot which is similar to the one which is proposed. Background data obtained at such a site would inherently account for parking lot emissions. If the first approach is not feasible, a second approach would be to add an arbitrary increment to the background concentration to account for the proposed lot. Limited data suggest that increments of 5 ppm and 2 ppm would be conservative values to add to the 1- and 8-hour background concentrations respectively.[20] Estimating background concentrations in the vicinity of proposed parking lots is illustrated in Example 7 in Section 4.6.

4.4 The Effect of Varying Automotive Operating Factors

The curves depicted in Figures 2-10 are appropriate for a national average mix of model year vehicles for calender year 1975. This mix is composed of 88 percent automobiles and 12 percent light-duty trucks. Twenty percent of this national mix is assumed to be operating from cold starts with ambient temperatures ranging from 68°F to 86°F. If the mixture of vehicles in the area of interest has different characteristics than those upon which Figures 2-10 are based, the estimates obtained using Sections 4.1 and 4.2 must be corrected. This section discusses correction factors needed to account for four such differences: fraction of cold starts, differing ambient temperatures, effect of automotive emission control programs, and the effect of local factors altering the vehicle mix.

4.4.1 Fraction of Vehicles Operating from a Cold Start

Table 1 presents a series of "cold start-cold temperature correction factors" which should be applied if the reviewer has reason to believe the assumption of 20 percent cold starts is inappropriate for the site being reviewed and/or temperatures outside the range of 68°-86°F are appropriate. Cold start-cold temperature correction factors should only be applied to the estimated 1- and 8-hour impact of

Table 1. COLD START CORRECTION FACTORS AT VARIOUS AMBIENT TEMPERATURES*

Percent of Cold-Operating Vehicles	Ambient Temperature		
	Cold (20°F)	Cool (50°F)	Warm (75°F)
0	.6	.8	.7
10	1.2	1.1	.9
20	1.7	1.3	1.0
30	2.2	1.6	1.1
40	2.8	1.8	1.3
50	3.3	2.1	1.4
60	3.8	2.3	1.5
70	4.3	2.6	1.7
80	4.9	2.8	1.8
90	5.4	3.1	1.9
100	5.9	3.3	2.0

*These correction factors are appropriate for cold start-cold temperature emissions for vehicles which are not equipped with catalysts. Emission factors for catalytically equipped vehicles may be estimated using the appropriate table in Supplement 5 to AP-42[26] and comparing the result with the 55 gm/mi factor assumed in Section 4.1.

nearby traffic. The estimated background concentration would already reflect the fraction of vehicles operating from cold start. If the cold soak period for a vehicle exceeds 4 hours and the vehicle passes in the vicinity of the receptor point of interest within 4 minutes, emissions from that vehicle may be appreciably greater than those from a warmed-up vehicle. The basis for the correction factors in Table 1 are discussed more fully in Section 6.2.

4.4.2 The Effect of Automotive Emission Control Programs

Table 2 presents correction factors to reflect the application of emission control programs. Emission control programs are categorized in three ways: control programs applied in low altitude areas, control programs applied in California (reflecting more stringent emission standards for a limited time) and control programs applied in high altitude areas.

The correction factors in Table 2 were obtained by taking the ratio of a CO emission factor for the calender year of interest to that for 1975 for a vehicle mix composed of 88 percent automobiles and 12 percent light-duty trucks and rounding to the nearest tenth. Emission factors for each calender year were estimated using guidance in Chapter 3, Supplement 5 to AP-42.[26] The national adjustment factors in Table 2 assume a CO emission standard of 15 gm/mi applies for 1975, 1976 and 1977 model vehicles and the statutory standard of 3.4 gm/mi applies thereafter. The California factors reflect the California interim standards through 1977.

The correction factors in Table 2 may be applied directly to the impact of nearby traffic estimated in Sections 4.1 and 4.2. Equation (4) should be used to apply the correction factors in Table 2 to estimated background concentrations.

TABLE 2. CORRECTION FACTORS REFLECTING EMISSION CONTROL PROGRAMS IN DIFFERENT AREAS*

Year	Low Altitude	High Altitude	California
1975	1.0	1.8	1.0
1976	0.9	1.6	0.8
1977	0.8	1.4	0.8
1978	0.7	1.2	0.6
1979	0.5	1.0	0.5
1980	0.4	0.8	0.4

*These correction factors reflect the imposition of interim Federal CO emission standards (for the low altitude and high altitude areas) through model year 1977 and the statutory standard thereafter. For California, the CO correction factors reflect the California interim standards through the 1977 model year and the statutory standards thereafter. Should amendments to the Clean Air Act proposed in March 1975 become law, correction factors for 1978 and later years may be altered. In the event Congress amends the Clean Air Act, this table should be altered accordingly. This may be done using Supplement 5 to AP-42.[26]

$$(cf)_{background} = \frac{(cf)_{year\ of\ interest}}{(cf)_{1975}} \quad (4)$$

Example 8 in Section 4.6 illustrates the application of cold start and emission control correction factors in the screening procedure.

4.4.3 Consideration of Other Factors Affecting Local Vehicle Operating Conditions

The emission factors which were used in deriving the curves in Figures 2, 3, 4 and 9 are based on average trip emission factors for national average mix of vehicles (by model year) composed of 88 percent autos and 12 percent light-duty trucks and metropolitan area driving cycles as described by the 1975 Federal Test Procedure.[27] Figures 6 and 7 are based on observed traffic at a signalized intersection.[21] Whenever data are available concerning local emission factors reflecting considerations other than cold start, cold temperature, altitude and control programs (e.g., prevailing local mixes of vehicles, driving cycles, steep grades), these should be substituted for the emission factors used in deriving the curves in Section 4.1. If such a procedure is followed, the estimates obtained using the curves should be multiplied by a "local factor" as determined with Equation (5).

$$lf = \frac{\text{(local emission factor for one year after the proposed source begins operation)}}{\text{(national average trip emission factor for one year after the proposed source begins operation)}} \quad (5)$$

4.5 Special Considerations for Event-Oriented Facilities

In defining volume demand, it is assumed that demands during a 1-hour period are evenly spread out over the hour (i.e., peak hour factor ≈ 1). This assumption may not be valid for event-oriented facilities. A prominent example of such a facility is a sports stadium. The peak impact on CO concentrations is likely to occur shortly after the event's conclusion when everybody tries to leave at once. Observations in the vicinity of stadiums[19] have indicated periods of extreme congestion for a fraction of an hour after the event with practically no traffic toward the end of the hour. Accordingly, the following procedure is suggested to determine whether key design and operating parameters are sufficient to avoid the threat to the 1-hour CO NAAQS in the vicinity of event-oriented indirect sources.

(a) For Signalized or Non-Signalized Exits from the Parking Lot

1. Obtain estimates of the traffic volume (V', vehicles) likely to utilize each exit gate.

2. Estimate time required to accommodate all vehicles wishing to use each gate:

$$T_i = \frac{V_i'}{c_i} \qquad (6)$$

where V_i' = traffic volume wishing to use gate i, vehicles

c_i = maximum capacity of gate (=(# of lanes)(average lane capacity)), veh/hr

T_i = time required to accommodate all vehicles wishing to use gate i, hr

3. Assume the volume demand is equal to the capacity (i.e., v/c = 1) for T and is zero for the remaining portion of the hour.

4. Obtain concentration from the appropriate ones of Figures 6-10 assuming the demand equals the capacity. Multiply the sum of the lane contributions by "T" and add background concentrations.

(b) For Nearby Intersections and at Midblock Sections

Unless the unused capacity of the road is very much greater than that of the exit from the source, follow the same procedure outlined above using the appropriate ones of Figures 2-10, only in step 3 assume the volume demand is equal to that generated by traffic which is not related to the source during the remainder of the hour. If the unused capacity of the access road greatly exceeds the exit capacity, analyze the roadway as would be done for a non-event source. Analysis of an event-oriented source is illustrated with Example 9 in Section 4.6.

4.6 Illustrative Examples of the Application of the Screening Procedure in Indirect Source Review

The purpose of this section is to provide numerical examples to better illustrate the screening procedure described in Sections 4.1 - 4.5. Nine examples, describing different facets of the screening procedure, are applied to the hypothetical source pictured in Figure 1. A tenth example, synthesizing the various features of the screening procedure, is then presented. Finally, an eleventh example is presented to illustrate the procedure for estimating representative concentrations along sidewalk centerlines should receptors of this nature be of interest for the source under review.

Example 1

(a) Purpose. The purpose of this example is to illustrate the use of Figures 2-5 to estimate the impact of freely flowing traffic on ambient 1-hour CO concentrations at nearby receptor sites.

(b) Problem. Suppose a receptor point is located a perpendicular distance of 17 meters from a mid-block location of a major street (e.g., location 1, Figure 1). Further, the receptor is north of the street. Highest estimated traffic demand occurring on the road during hours in which the source is operating is estimated to be 2400 vph. This demand results from existing traffic and the projected demand attributable to the proposed source. During the hour of interest 60% of the traffic is assumed to be traveling west. Capacity of the lanes at mid-block is estimated as 1000 vph/lane. There are 4 lanes and each lane is assumed to be 4 meters wide. What is the maximum impact of the estimated traffic on ambient 1-hour CO concentrations at the specified receptor point?

(c) Solution.

(1) Estimate the demand per lane by noting that the total demand is 2400 vph. Since 60% of this traffic is traveling west, the demand in lanes (1) and (2) is:

$$v = \frac{(.60)\ (2400\ \text{vph})}{(2\ \text{lanes})} = 720\ \text{vph/lane}$$

Similarly, the demand in lanes (3) and (4) is:

$$v = (.40)\ (2400)\ (1/2) = 480\ \text{vph/lane}$$

(2) Estimate the demand-capacity ratio for each lane -

For lanes (1) and (2) v/c = 720/1000 = .72

For lanes (3) and (4) v/c = 480/1000 = .48

(3) Since location 1 is near a midblock location of a major street, Figures 3 and 5 are applicable. From Figure 3, note that if each lane were 10 m from the receptor, the following impacts would be estimated:

x_1 = 4.6 ppm

x_2 = 4.6 ppm

x_3 = 2.4 ppm

x_4 = 2.4 ppm

(4) However, the nearest lane, lane 1, is 17 meters from the receptor. Since each lane is 4 meters wide, lane (2) is 21 meters from the receptor; lane (3) is 25 meters and lane (4) is 29 meters from the receptor. This information, together with the calculations in step (3) above, is used in Figure 5 to estimate the impact of the street on the receptor at location 1 in Figure 1.

From Figure 5, note that at a 17 meter distance the impact of a lane of traffic is 0.75 that at 10 meters. Similarly at 21 meters, 25 meters and 29 meters, the impact is .66, .60 and .55 of the 10 meter impact respectively.

Therefore,

$x_1 = (.75)\ (4.6) = 3.5$

$x_2 = (.66)\ (4.6) = 3.0$

$x_3 = (.60)\ (2.4) = 1.4$

$x_4 = (.55)\ (2.4) = 1.3$

Total impact of the street = 9.2 ~ 9 ppm

Example 2

(a) Purpose. The purpose of this example is to illustrate the use of Figures 6-8 to estimate the maximum impact of traffic at a leg of a signalized intersection on ambient 1-hour CO concentrations at a nearby receptor point.

(b) Problem. A receptor point of interest is located 20 m north of the east leg of the signalized intersection pictured at location 2 in Figure 1. Traffic demand in lanes (1) and (2) is 720 vph/lane. Traffic demand in lanes (3) and (4) is 480 vph/lane. The east leg of the intersection has 4 lanes and each lane is 4 meters wide. The signal at location 2 is a traffic-actuated one. What is the maximum impact of the estimated traffic on ambient 1-hour CO concentrations at the designated receptor?

(c) Solution.

(1) Since the signal is a traffic actuated one and there is no information given concerning demands at the intersection's other legs, assume G/Cy for the east leg's through traffic is 0.6 as suggested in Section 4.1.2.

(2) Lanes (1) and (2) constitute the intersection approach and hence are upstream from the intersection. Enter the abscissa in Figure 6 at a demand of 720 vph/lane and note the intersection with the G/Cy = 0.6 curve.

From Figure 6,

x_1 = 10.4 ppm

x_2 = 10.4 ppm

(3) Lanes (3) and (4) are downstream from the intersection, so Figure 7 must be used. Since the east leg is on a major street, and v/c = .48 use Table 3 to assume a cruise speed of 30 mph will be attained. Entering the abscissa at 480 vph, note that

x_3 = 2.5 ppm

x_4 = 2.5 ppm

(4) The estimates in steps (2) and (3) would be appropriate if the distance between the receptor and each lane were 10 meters. However, lanes (1) - (4) are 20, 24, 28 and 32 meters respectively from the receptor site. Thus Figure 8 must be used to adjust the estimates obtained in steps (2) and (3). The "upstream curve" applies for lanes (1) and (2) since they are upstream from the intersection. The "downstream curve" applies for lanes (3) and (4). Combining the information obtained from steps (2) and (3) with that in Figure 8, note that:

$x_1 = (.59)\ (10.4) = 6.1$

$x_2 = (.49)\ (10.4) = 5.1$

$x_3 = (.54)\ (2.5) = 1.4$

$x_4 = (.48)\ (2.5) = 1.2$

Total impact of the intersection leg = 13.8 ~ 14 ppm

Example 3

(a) Purpose. The purpose of this example is to illustrate the use of Figures 9, 7 and 10 to estimate the maximum impact of traffic at a leg of a non-signalized intersection on ambient 1-hour CO concentrations at nearby receptor points.

(b) Problem. A receptor point is located 15 meters from the leg of an intersection of the major exit/entrance and a ring road within an indirect source parking lot as shown at location 3 in Figure 1. If the capacity of the 2-lane intersection leg is 300 vph/lane and the estimated demand using the leg is 250 vph in each direction, what is the impact of this traffic on ambient 1-hour CO concentrations at the receptor point. Each lane is estimated to be 3 meters wide.

(c) Solution.

(1) Referring to location 3 in Figure 1, traffic in lane (5) is upstream from the intersection and traffic in lane (6) is downstream. Therefore, Figures 9 and 10 must be used for lane (5) and Figures 7 and 10 for lane (6).

(2) The demand-capacity ratio for lane (5) is:

$$v/c = \frac{250}{300} = .83$$

From Figure 9, the impact of lane (5) on a receptor 10 meters from the lane would be:

$$x_5 = 14.5 \text{ ppm}$$

(Note from Figure 9 that if v/c had been less than 0.38, the c = 300 vph curve would have determined lane (5)'s impact on the ambient CO concentration at the receptor point.)

(3) Using the 15 mph cruise curve in Figure 7, as suggested in Section 4.1.2, x_6 = 2.6 ppm.

(4) Since the receptor is 15 meters from lane (5) and 18 meters from lane (6), Figure 10 is needed. The "upstream curve" in Figure 10 applies for lane (5), while the "downstream curve" is appropriate for lane (6). Combining the information in steps (2) and (3) with that in Figure 10,

$$x_5 = (.75)\ (14.5) = 10.9$$

$$x_6 = (.74)\ (2.6) = 1.9$$

Total impact of the intersection leg = 12.8 ~ 13 ppm

Example 4

(a) Purpose. The purpose of this example is to illustrate the derivation and use of meteorological persistence factors in estimating the impact of nearby traffic on 8-hour ambient CO concentrations at the receptor points described in Examples 1-3.

(b) Problem. Peak 8-hour traffic demand on the major street depicted at locations 1 and 2 in Figure 1 is estimated to be 2000 vph. Traffic is assumed to be split 50-50 in each direction. Peak traffic demand on lanes (5) and (6) within the proposed parking lot is estimated to be 200 vph/lane for an 8-hour period. During a two week air quality monitoring study conducted by the applicant at a proximate site (Site A) 25 m north of lane (1), a maximum 1-hour CO concentration of 8 ppm is observed during hours in which the source would operate. The corresponding traffic flow observed during this hour was 1000 vph in each direction. The maximum 8-hour concentration observed including operating hours was 3 ppm. Eight-hour traffic demand during this period was observed to be 1600 vph, with 800 vph in each direction. The terrain and buildings at locations 1 and 2 are similar in size and shape. However, location 3 is considerably more level and open. What is the impact of nearby traffic on 8-hour ambient CO concentrations at receptor points R1, R2 and R3 in Figure 1?

(c) Solution.

(1) Estimate the peak 8-hour traffic demand in traffic lanes (1) - (6).

$v_1 = \frac{1000}{2} = 500$ vph and $v/c = 0.5$

$v_2 = 500$ vph and $v/c = 0.5$

$v_3 = 500$ vph and $v/c = 0.5$

$v_4 = 500$ vph and $v/c = 0.5$

$v_5 = 200$ vph and $v/c = .67$

$v_6 = 200$ vph and $v/c = .67$

(2) Estimate 1-hour concentrations at each receptor point, using the 8-hour demands.

Point R1:
From the c = 1000 vph curve in Figure 3,

$x_1 = 2.5$ ppm
$x_2 = 2.5$ ppm
$x_3 = 2.5$ ppm
$x_4 = 2.5$ ppm

Since lane (1) is 17 meters from R1 and lanes (2) - (4) are 21, 25 and 29 meters away respectively, Figure 5 is used to show

$x_1 = (.75)\ (2.5) = 1.9$

$x_2 = (.67)\ (2.5) = 1.7$

$x_3 = (.60)\ (2.5) = 1.5$

$x_4 = (.55)\ (2.5) = 1.4$

Total 1-hour impact @ R1 = 6.5 ppm

Point R2:
From Figure 6,

$x_1 = 7.4$ ppm; $x_2 = 7.4$ ppm

From Figure 7,

$x_3 = 2.6$ ppm; $x_4 = 2.6$ ppm

Adjusting these values for the appropriate receptor distance with Figure 8,

$\chi_1 = (.59)\ (7.4) = 4.4$

$\chi_2 = (.49)\ (7.4) = 3.6$

$\chi_3 = (.54)\ (2.6) = 1.4$

$\chi_4 = (.49)\ (2.6) = 1.3$

Total 1-hour impact @ R2 = 10.7 ppm

Point R3:
From Figures 9 and 10, $\chi_5 = 4.6$ ppm

From Figures 7 and 10, $\chi_6 = 1.8$ ppm

Total 1-hour impact @ R3 = 6.4 ppm

(3) Estimate 8-hour meteorological persistence factor.

Point R1:
Using Equation (1) at location 1, where Monitoring Site A is located,

$$p \sim \left[\frac{3\ \text{ppm}}{8\ \text{ppm}}\right] \left(\frac{2000\ \text{vph}}{1600\ \text{vph}}\right) \tag{1}$$

$p = .47 \sim .5$

Point R2:
Since variation in traffic volume on the east leg of the intersection is likely to be similar to that at location 1 and the location's aerodynamic characteristics are similar, use a persistence factor of p = 0.5 at location 2 in Figure 1 as well.

Point R3:
Since there have been no traffic observations at a similar but existing source and the roughness characteristics are different at location 3 than they are elsewhere in Figure 1, assume a meteorological persistence factor of 0.6 as suggested in Section 4.2.

(4) Apply meteorological persistence factors to estimated 1-hour impacts to estimate the 8-hour impacts at the selected receptor points.

Point R1:

$\chi = (6.5)\ (0.5) = 3.3 \sim 3$ ppm

Point R2:

$\chi = (10.7)\ (0.5) = 5.4 \approx 5$ ppm

Point R3:

$\chi = (6.4)\ (0.6) = 3.8 \approx 4$ ppm

Example 5

(a) Purpose. The purpose of this example is to illustrate the manner in which background concentrations of CO observed near the proposed site during a limited period can be seasonally adjusted and used to estimate maximum background concentrations appropriate for use in the screening procedure. The example is subdivided into three parts. The first part assumes there is a historical monitoring site for CO operating and that hourly data are available. Part 2 assumes that only maximum 1- and 8-hour values are available at the historical site. Part 3 assumes that there are no data available from a historical station.

Part 1

(b) Problem. Monitoring Site B, at location 3 in Figure 1, is situated at least 100 meters from any major road, and is operated for a 14 day period. Monitoring Site C (not shown in Figure 1) is a CO monitoring station which is maintained independently and has been operating for a year. During the 14 day period in which Station B is operating, the maximum 1- and 8-hour CO concentrations observed at this site during hours in which the proposed site would operate are 4 ppm and 2 ppm respectively. At Site C the maximum 1- and 8-hour concentrations observed during the proposed source's operating hours are 16 ppm and 4 ppm respectively. During the past year the maximum 1- and 8-hour concentrations observed at Site C during the source's operating hours are 24 ppm and 6 ppm respectively. What background concentrations should be assumed for the source in the screening procedure?

(c) Solution.

(1) Estimate 1-hour background concentration with Equation (2).

Using Equation (2),

$$\chi_b = \frac{(4\ \text{ppm})\ (24\ \text{ppm})}{(16\ \text{ppm})} = 6\ \text{ppm} \qquad (2)$$

(2) Estimate 8-hour background concentration with Equation (2) in Section 4.3.1.

$$\chi_b = \frac{(2\ \text{ppm})\ (6\ \text{ppm})}{(4\ \text{ppm})} = 3\ \text{ppm} \qquad (2)$$

Part 2

(b) Problem. Suppose only maximum 1- and 8-hour concentration data are readily available from the historical monitoring site. These data indicate the following for Site C:

Maximum 1-hour CO concentration during 14 day period is 27 ppm.
Maximum 8-hour CO concentration during 14 day period is 7 ppm.
Maximum 1-hour CO concentration during past year is 31 ppm.
Maximum 8-hour CO concentration during past year is 12 ppm.

(c) Solution. Use Equation (2a) in Section 4.3.1.

1-hour

$$\chi_b = (4\ \text{ppm})\ \left(\frac{31\ \text{ppm}}{27\ \text{ppm}}\right) = 4.6 \sim 5\ \text{ppm} \qquad (2a)$$

8-hour

$$\chi_b = (2\ \text{ppm})\ \left(\frac{12\ \text{ppm}}{7\ \text{ppm}}\right) = 3.4 \sim 3\ \text{ppm} \qquad (2b)$$

Part 3

(b) Problem. Suppose Site C does not exist. Assume, for illustrative purposes, the proposed source is located in north central North Carolina and the monitoring data at Site B were obtained during the spring.

(c) Solution.

Note from Figure 43 in AP-101[25] that the upper tenth percentile $\overline{\frac{\chi}{Q}}$ in central North Carolina in spring is estimated as about 400 sec/m. Also note from Figure 45 that the worst season in terms of pollution potential in this part of the country is autumn, where $\overline{\frac{\chi}{Q}} \sim 600$ sec/m.

(2) Use Equation (3) in Section 4.3.1 to estimate 1- and 8-hour background concentrations.

1-hour

$$\chi_b = (4\ \text{ppm})\ \left(\frac{600\ \text{sec/m}}{400\ \text{sec/m}}\right) \sim 6\ \text{ppm} \qquad (3)$$

8-hour

$$x_b = (2 \text{ ppm}) \left(\frac{600 \text{ sec/m}}{400 \text{ sec/m}}\right) = 3 \text{ ppm} \qquad (3)$$

Example 6

(a) Purpose. The purpose of this example is to illustrate how air quality data obtained at proximate monitoring sites (i.e. within 100 meters of the roadway being evaluated) may be used in the screening procedure to "calibrate" the curves in Figures 2-10 and to estimate maximum 1- and 8-hour ambient concentrations using the screening procedure.

(b) Problem. Suppose the only available air quality data available are from monitoring Point A, the proximate monitoring site described in Example 4. Pertinent data are as follows:

- Point A is located 25 meters from the street being examined (Example 4);
- Maximum 1-hour CO concentration observed during the proposed source's monitoring hours is 8 ppm (Example 4);
- Maximum 8-hour CO concentration observed during the proposed source's monitoring hours is 3 ppm (Example 4);
- Maximum expected 1-hour traffic demand occurring on the major street during operating hours after the source is built is $v_1 = v_2 = 720$ vph and $v_3 = v_4 = 480$ vph (Example 1);
- Maximum expected 8-hour traffic demand occurring on the major street during operating hours after the source is built is $v_1 = v_2 = v_3 = v_4 = 500$ vph (Example 4);
- 1-hour traffic demand corresponding to the highest observed 1-hour CO concentration during source operating hours was $v_1 = v_2 = v_3 = v_4 = 500$ vph (Example 4);
- 8-hour traffic demand corresponding to the highest observed 8-hour CO concentration during source operating hours was $v_1 = v_2 = v_3 = v_4 = 400$ vph (Example 4).

How can the CO data collected at proximate Site A be used to estimate maximum 1- and 8-hour ambient CO concentrations occurring at receptor site R1 in Figure 1?

(c) Solution.

(1) Seasonally-adjust the monitoring data.

From Part 1 of Example 5 and the maximum 1- and 8-hour CO concentrations of 8 ppm and 3 ppm observed at Site A;

$$\text{1-hour:} \quad x_b = (8 \text{ ppm}) \left(\frac{24 \text{ ppm}}{16 \text{ ppm}}\right) = 12 \text{ ppm} \qquad (2)$$

$$\text{8-hour:}\quad \chi_b = (3\ \text{ppm})\left(\frac{6\ \text{ppm}}{4\ \text{ppm}}\right) = 4.5\ \text{ppm} \qquad (2)$$

(2) Estimate the contributions of each lane to the observed concentrations at the receptor site.

Since the monitoring and receptor sites are located near a mid-block section of a major street, Figures 3 and 5 are applicable. Note that Site A is 25 m, 29 m, 33 m and 37 m from lanes (1) - (4) respectively. Using Figures 3 and 5, the following contributions at Site A are attributable to each lane.

1-hour - Site A

$$\chi_1 = (12)\left[\frac{.60}{(.60+.55+.50+.46)/4}\right]\left[\frac{2.5}{(2.5+2.5+2.5+2.5)}\right] = 3.4$$

Where "12" is the seasonally-adjusted observed 1-hour maximum concentration at Site A.

The terms in the first square brackets are distance-decay factors for the appropriate distances and are obtained from Figure 5. The purpose of the first square brackets is to weight the nearer lanes' impacts more heavily.

The terms in the second set of square brackets are intended to weight the lanes' impacts according to the demand-capacity ratio observed in each lane. The "2.5" number is the CO concentration corresponding to the observed 1-hour v/c ratio of 0.5 in lane (1) estimated from Figure 3. Since the same v/c was observed in each lane in this example, the numbers in the denominator are all "2.5" as well.

Similarly,

$$\chi_2 = (12)\left[\frac{.55}{.53}\right]\left[\frac{1}{4}\right] = 3.1$$

$$\chi_3 = (12)\left[\frac{.50}{.53}\right]\left[\frac{1}{4}\right] = 2.8$$

$$\chi_4 = (12)\left[\frac{.46}{.53}\right]\left[\frac{1}{4}\right] = 2.6$$

8-hour - Site A

$$\chi_1 = (4.5)\left[\frac{.60}{.53}\right]\left[\frac{2.0}{(2.0+2.0+2.0+2.0)}\right] = 1.3$$

The "2.0" in the second pair of square brackets results from applying Figure 3 for an observed 8-hour v/c of 0.4 in each lane.

$x_2 = (4.5)\ [\frac{.55}{.53}]\ [\frac{1}{4}] = 1.2$

$x_3 = (4.5)\ [\frac{.50}{.53}]\ [\frac{1}{4}] = 1.1$

$x_4 = (4.5)\ [\frac{.46}{.53}]\ [\frac{1}{4}] = 1.0$

(3) Estimate the "calibrated" contribution of each lane at a 10 meter distance using Figure 5.

1-hour

$x_1 = (\frac{3.4}{.60}) = 5.6$

$x_2 = (\frac{3.1}{.55}) = 5.6$

$x_3 = (\frac{2.8}{.50}) = 5.6$

$x_4 = (\frac{2.6}{.46}) = 5.6$

8-hour

$x_1 = (\frac{1.3}{.60}) = 2.2$

$x_2 = (\frac{1.2}{.55}) = 2.2$

$x_3 = (\frac{1.1}{.50}) = 2.2$

$x_4 = (\frac{1.0}{.46}) = 2.2$

(4) Note the incremental change in the impact of traffic in each lane at the 10 meter distance resulting from the difference between observed v/c's and the maximum projected v/c's.

1-hour

For lanes (1) and (2), projected v/c = .72 while observed v/c = .5.

For lanes (3) and (4), projected v/c = .48 while observed v/c = .5.

Using the "calibration" version of Figure 3,

$\Delta x_1 = \Delta x_2 = [4.6 - 2.5]\ (\frac{5.6}{2.5}) = 4.7$

$\Delta x_3 = \Delta x_4 = [2.5 - 2.5]\ (\frac{5.6}{2.5}) = 0$

8-hour

For lanes (1) - (4), projected v/c = 0.5, while observed v/c = 0.4.

Using the "calibration" version of Figure 3,

$$\Delta\chi_1 = \Delta\chi_4 = \Delta\chi_2 = \Delta\chi_3 = [2.5 - 2.0]\ [0.5]\ (\frac{2.0}{2.1}) = 0.2$$

The "0.5" in the above equation is the meteorological persistence factor estimated in Example 4. This should be used, since Figure 3 is applicable for 1-hour concentrations. It was not necessary to use the persistence factor in Steps (2) and (3) because the derived values were based on 8-hour observations.

(5) Combine the information in Steps (3) and (4) to estimate the projected maximum concentrations attributable to each lane at a 10 meter distance from each lane.

1-hour

$\chi_1 = 5.6 + 4.7 = 10.3$

$\chi_2 = 5.6 + 4.7 = 10.3$

$\chi_3 = 5.6 + 0 = 5.6$

$\chi_4 = 5.6 + 0 = 5.6$

8-hour

$\chi_1 = 2.2 + 0.2 = 2.4$

$\chi_2 = 2.2 + 0.2 = 2.4$

$\chi_3 = 2.2 + 0.2 = 2.4$

$\chi_4 = 2.2 + 0.2 = 2.4$

(6) Use Figure 5 and the information in Step (5) to estimate the projected maximum 1- and 8-hour concentrations at receptor R1, located 17 meters from the nearest lane.

1-hour

$x_1 = (.75)\ (10.3) = 7.7$

$x_2 = (.66)\ (10.3) = 6.8$

$x_3 = (.60)\ (5.6) = 3.4$

$x_4 = (.55)\ (5.6) = 3.1$

$\text{Sum} = 21.0$

Therefore, the estimated peak 1-hour ambient concentration at receptor point R1 during th proposed source's operating hours is 21 ppm.

8-hour

$x_1 = (.75)\ (2.4) = 1.8$

$x_2 = (.66)\ (2.4) = 1.6$

$x_3 = (.60)\ (2.4) = 1.4$

$x_4 = (.55)\ (2.4) = 1.3$

$\text{Sum} = 6.1$

Therefore, the estimated peak 1-hour ambient concentration at receptor site R1 including the source's operating hours is 20 ppm, and the estimated peak 8-hour ambient concentration is 6 ppm.

Example 7

(a) Purpose. The purpose of this example is to illustrate the use of observed background concentrations at representative monitoring sites in the screening procedure to estimate peak projected 1- and 8-hour ambient CO concentrations at selected receptor points. The example is divided into two parts. The first part concerns receptors which are not located within or immediately downwind from a proposed parking lot. The second part deals with a receptor point located within a proposed parking lot.

(b) Problem. After a joint review between the applicant and reviewing agency, three sensitive receptor points are selected. These are pictured as R1, R2 and R3 in Figure 1. After seasonally adjusting background concentrations at representative monitoring Site B (as shown in Example 5), the maximum background concentrations appropriate for locations 1, 2 and 3 in Figure 1 are estimated to be 6 ppm for 1-hour concentrations, and 3 ppm for 8-hour concentrations. How can this information be used in the screening procedure to estimate maximum 1- and 8-hour CO concentrations at receptor sites R1, R2 and R3?

(c) Solution.

Part 1-- Receptors R1 and R2

(1) Recall the maximum projected impacts estimated from previous examples.

At R1

For 1-hour, χ = 9.2 ppm (Example 1)

For 8-hour, χ = 3.3 ppm (Example 4)

(2) Therefore, the maximum estimated ambient CO concentration at R1 is:

For 1-hr: $\chi = 9.2 + 6 = 15.2 \sim \underline{15\text{ ppm}}$

For 8-hr: $\chi = 3.3 + 3 = 6.3 \sim \underline{6\text{ ppm}}$

At R2

(1) For 1-hour, χ = 13.8 ppm (Example 2)

For 8-hour, χ = 5.4 ppm (Example 4)

(2) Therefore, the maximum estimated ambient CO concentration at R2 is:

For 1-hr: $\chi = 13.8 + 6 = 19.8 \sim \underline{20\text{ ppm}}$

For 8-hr: $\chi = 5.4 + 3 = 8.4 \sim \underline{8\text{ ppm}}$

Part 2--Receptor R3

(1) Recall the maximum projected impacts estimated from previous examples.

For 1-hour, $\chi = 12.8$ ppm (Example 3)

For 8-hour, $\chi = 3.8$ ppm (Example 4)

(2) Since it was not feasible to monitor background air quality within an existing source's parking lot in this example, add incremental impacts of 5 ppm and 2 ppm to the seasonally-adjusted 1- and 8-hour background concentrations.

For 1 hour: $\chi_b = 6 + 5 = 11$ ppm

For 8 hour: $\chi_b = 3 + 2 = 5$ ppm

(3) Therefore, the maximum estimated CO concentration at R3 is:

For 1-hr: $\chi = 12.8 + 11 = 23.8 \approx \underline{24\text{ ppm}}$

For 8-hr: $\chi = 3.8 + 5 = 8.8 \approx \underline{9\text{ ppm}}$

Example 8

(a) Purpose. The purpose of this example is to show how the effect of CO emission factors differing from those assumed in Figures 2, 3, 4, 6, 7 and 9 is accounted for in the screening procedure. The example is divided into two parts. The first part deals specifically with the impact of national emission control programs by assuming that the emission factors for 1975, used in deriving Figures 2-4, 6, 7 and 9 are not appropriate. The second part shows how the effect of differing local conditions can be accounted for.

Part 1

(b) Problem. The indirect source pictured in Figure 1 is scheduled to begin operation in 1976. What are the estimated maximum 1- and 8-hour ambient CO concentrations which are of interest at receptor points R1, R2 and R3?

(c) Solution.

(1) Since the source begins operation in 1976 and the time of interest is 1 year after the source begins operation (i.e., it is assumed that the source will not be entirely operational immediately), the critical time is 1977.

(2) From the second column in Table 2 in Section 4.4.2, the appropriate correction factor reflecting the status of emission control programs in 1977 is 0.8.

(3) Tabulate the information in Example 7 as shown below:

Point	Sampling Time	Component		Estimated Max. Conc.
		Impact of Nearby Traffic	Background	
R1	1-hr. 8-hr.	9.2 3.3	6 3	15.2 6.3
R2	1-hr. 8-hr.	13.8 5.4	6 3	19.8 8.4
R3	1-hr. 8-hr.	12.8 3.8	11 5	23.8 8.8

(4) Since ambient CO concentrations are almost entirely attributable to automotive emissions, both the background and nearby components can be multiplied by 0.8.

Therefore, in 1977

At R1

For 1-hr: $\chi = (15.2)(.8) = 12.2 \approx \underline{12\ \text{ppm}}$

For 8-hr: $\chi = (6.3)(.8) = 5.0 \approx \underline{5\ \text{ppm}}$

At R2

For 1-hr: $\chi = (19.8)(.8) = 15.8 \approx \underline{16\ \text{ppm}}$

For 8-hr: $\chi = (8.4)(.8) = 6.7 \approx \underline{7\ \text{ppm}}$

At R3

For 1-hr: $\chi = (23.8)(.8) = 19.0 \approx \underline{19\ \text{ppm}}$

For 8-hr: $\chi = (8.8)(.8) = 7.0 \approx \underline{7\ \text{ppm}}$

Part 2

(b) Problem. Suppose the peak demand at the source described in Part 1 occurs during a time of year when the ambient temperature may be 20°F. Suppose further it is assumed that the vehicles traveling on the major street (e.g., at locations 1 and 2 in Figure 1) are all sufficiently warmed up so that the percent of cold starts is zero. What are the maximum 1- and 8-hour ambient CO concentrations at receptors R1, R2 and R3 during hours in which the proposed source will operate?

(c) Solution.

(1) Refer to the table presented in Part 1. Note that the background concentrations are based on observed air quality data. Thus, the background component is unaffected by assumptions concerning percentage of cold starts and altitude. Therefore, the background component is only affected by the effect of emission controls, while the impact of nearby traffic is affected by local emission peculiarities in addition to control programs.

(2) Note from Table I in Section 4.4.1, the cold start-cold temperature correction factor to be applied to the impact of nearby traffic at receptors R1 and R2 is 0.6, and the cold temperature correction factor at receptor R3 is 1.7.

(3) Therefore, in 1977, with the assumptions which have been made about the percentage of cold starts and cold ambient temperatures,

At R1

For 1-hr: $\chi = (9.2)\ (.8)\ (.6) + (6)\ (.8) = 9.2 \sim \underline{9 \text{ ppm}}$

For 8-hr: $\chi = (3.3)\ (.8)\ (.6) + (3)\ (.8) = 4.0 \sim \underline{4 \text{ ppm}}$

At R2

For 1-hr: $\chi = (13.8)\ (.8)\ (.6) + (6)\ (.8) = 11.4 \quad \underline{11 \text{ ppm}}$

For 8-hr: $\chi = (5.4)\ (.8)\ (.6) + (6)\ (.8) = 7.4 \sim \underline{7 \text{ ppm}}$

At R3

For 1-hr: $\chi = (12.8)\ (.8)\ (1.7) + (11)\ (.8) = 26.2 \sim \underline{26 \text{ ppm}}$

For 8-hr: $\chi = (3.8)\ (.8)\ (1.7) + (5)\ (.8) = 9.2 \sim \underline{9 \text{ ppm}}$

Note: No correction factor for percentage cold starts is used at location 3 (i.e., 20 percent of the vehicles are assumed to operate from cold starts).

Example 9

(a) Purpose. The purpose of this example is to illustrate the application of the screening procedure to estimate the maximum ambient 1-hour CO concentration likely in the vicinity of a proposed event-oriented indirect source.

(b) Problem. Suppose the source pictured in Figure 1 is to be a sports stadium operating in 1976. Seasonally-adjusted 1-hour background concentrations are assumed to be 6 ppm at receptors R1 and R2, using one of the approaches described in Example 5. The following estimates are made regarding the traffic volume generated by the source:

Lane (1): $V'_1 = 220$ vehicles

Lane (2): $V'_2 = 220$ vehicles

Lane (3), lane (4): $V'_3 = V'_4 = 0$ vehicles

Lane (5) $V'_5 = 200$ vehicles

Lane (6) $V'_6 = 0$ vehicles

Assume 50 percent of the vehicles are operating under cold start conditions by the time location 3 is reached and 0 percent are operating under cold start conditions at locations 1 and 2. Assume existing demand on lanes (1) - (4) is 500 vph/lane. Assume the ambient temperature during the period of peak demand is about 50°F.

(c) Solution.

At R1

(1) Estimate impact without source. Note that without the source, v/c = 0.5 for lanes (1) - (4). Thus from Figure 3, the impact of each of these lanes on a receptor 10 meters from each is 2.5 ppm.

(2) Estimate unused capacity. Since existing volume is 500 vph in each lane, and the capacity in each lane is 1000 vph, unused capacity is 500 vph/lane.

(3) Estimate the time required for vehicles exiting from the source and using lanes (1) and (2) to be accommodated. Use Equation (6).

$$\text{For each lane; } T = \frac{220}{500} = 0.44 \text{ hours} \qquad (6)$$

(4) Therefore for lanes (1) and (2) assume v/c = 1 for 0.44 hour and v/c = 0.5 for 0.56 hour. For lanes (3) and (4), v/c = 0.5 for the entire hour.

Thus, using Figure 3 for a 10 meter distance, For lanes (1) - (2) $\chi = (2.5)\ (.56) + (10.9)\ (.44) = 6.2$ ppm

(5) Using Figure 5 to estimate the impact at R1,

$\chi_1 = (6.2)\ (.75) = 4.7$

$\chi_2 = (6.2)\ (.66) = 4.1$

$\chi_3 = (2.5)\ (.60) = 1.5$

$\chi_4 = (2.5)\ (.55) = 1.4$

Total impact of nearby traffic at R1 = 11.7 ppm

(6) Apply cold start-cold temperature correction factor.

From Table 1, K = 0.8

Therefore,

Total impact @ R1 = (0.8) (11.7) = 9.4

(7) Add background concentration and apply correction factor to reflect the status of emission control programs in 1976 to estimate maximum 1-hour ambient CO concentration expected at the receptor.

χ_b = 6 ppm, and the appropriate correction factor is 0.9 (from Table 2).

Therefore, at R1:

$\chi = (9.4 + 6)\ (0.9) = 13.9 \sim$ 14 ppm

At R2

(1) Assume, for simplicity, that the intersection approach capacity is identical to mid-block capacity 1000 vph/lane.

(2) Therefore, unused capacity at the approach (i.e. lanes (1) and (2)) is 500 vph/lane.

(3) Therefore, $T = (\frac{220}{500}) = 0.44$ hours (6)

Note that if the intersection approach capacity were less than 1000 vph/lane, the proportion of the hour (T) in which demand equals or exceeds capacity would be greater.

(4) For lanes (1) and (2) assume v = 1000 vph for 0.44 hr. and is 500 vph for 0.56 hr. Assume v = 500 vph the entire hour for lanes (3) and (4).

(5) Using Figure 6 to estimate the impact of lanes (1) and (2) at a 10 meter distance, and Figure 7 to estimate the impact of lanes (3) and (4) at a 10 m distance,

$$x_1 = (.44)\ (15) + (.56)\ (7.4) = 10.7$$

$$x_2 = 10.7$$

$$x_3 = 2.7$$

$$x_4 = 2.7$$

Using Figure 8 to estimate the impact at R2,

$$x_1 = (10.7)\ (.58) = 6.2$$

$$x_2 = (10.7)\ (.50) = 5.4$$

$$x_3 = (2.7)\ (.54) = 1.5$$

$$x_4 = (2.7)\ (.48) = 1.3$$

Total impact of nearby traffic at R2 = 14.4 ppm

(6) Applying the apprpriate cold start correction factor,

Total impact @ R2 = (14.4) (.8) = 11.5

(7) Thus the maximum 1-hour CO concentration at receptor R2 in 1976 is estimated as:

$$\chi = (11.5 + 6)\ (0.9) = 15.8 \sim \underline{16\ \text{ppm}}$$

At R3

(1) From Example 3, note that the capacity of lane (5) is 300 vph.

(2) This step is not necessary at location 3, because all of the traffic in lane (5) is assumed to be generated by the proposed source.

(3) $T = (\frac{200}{300}) = 0.67$ hours (6)

(4) For lane (5), v/c = 1 for .67 hour and is 0 for the remainder of the hour. For lane (6), v = 0 for the entire hour.

(5) Using Figures 9 and 10 to estimate the impact of traffic in lane (5) at receptor R3,

$$\chi_5 = (34)\ (.67)\ (.74) = 16.9$$

(6) Note from Table 1, Section 4.4.1 that the cold start correction factor, K for 50% cold starts is 2.1.

Thus, $\chi_5 = (2.1)\ (16.9) = 35.5$

(7) Combining the approaches illustrated in Example 5 with the knowledge that traffic at location 3 is only present for .67 of an hour,

$$\chi_b = 6 + (5)\ (.67) = 9.3$$

Thus, $\chi = (35.5 + 9.3)\ (0.9) = 40.3 \approx \underline{40\ \text{ppm}}$

Example 10

(a) Purpose. The purpose of this example is to synthesize the points illustrated in the previous nine examples so that the estimation techniques which have been described may be presented in the order in which they may frequently be applied in the screening procedure.

(b) Problem. Figure 1 depicts a non-event source scheduled to begin operation in 1976. The source is in a low altitude area outside of California. It is of interest to estimate maximum 1- and 8-hour ambient CO concentrations at points R1, R2 and R3 during hours in which the source will operate. The table on the following page tabulates pertinent information needed to apply the screening approach. This table consolidates information presented in the problem statements of Examples 1, 3, 4, 5 and 8.

(c) Solution.

(1) Estimate seasonally-adjusted background concentrations using the information in columns (2) - (7).

For 1-hr: $\chi_{b1} = \dfrac{(4)\ (24)}{(16)} = \underline{6\ \text{ppm}}$

For 8-hr: $\chi_{b8} = \dfrac{(2)\ (6)}{(4)} = \underline{3\ \text{ppm}}$

(See Example 5 for details.)

(2) Estimate 1-hr impact of nearby traffic at points R1, R2 and R3 using information in columns (8), (9), (10) and (12).

Input Information Used in the Application of the CO Screening Procedure

(1) Type of Background Monitoring Site	(2) Peak Concs.	(3) Observed at Site, ppm	(4) Peak Obs.@ Historical Site, ppm	(5)	(6) Max. Obs. @ Historical Site in past year, ppm	(7)	(8) Traffic Lane Desig-cation	(9) Lane Width m	(10) Projected 1-hr peak Demand vph	(11) Projected 8-hr peak Demand vph	(12) Capacity vph	(13) Maximum Observed 1-hr Conc.@ a Proximate Site, ppm	(14) Maximum Observed 8-hr Conc.@ a Proximate Site, ppm	(15) Observed 1-hr Volume, vph	(16) Observed 8-hr Volume, vph	(17) % Cold Starts	(18) Ambient Temp.	(19) Year of Interest
	1-hr	8-hr	1-hr	8-hr	1-hr	8-hr												
Representative	4	2	16	4	24	6	1	4	720	500	1000	8	1	500	400	0	Cold (20°F)	1977
							2	4	720	500	1000			500	400	0		
							3	4	480	500	1000			500	400	0		
							4	4	480	500	1000			500	400	0		
							5	3	250	200	300			---	---	20		
							6	3	250	200	300			---	---	20		

At R1 from Figures 3 and 5,

$x_1 = (.75)\ (4.6) = 3.5$

$x_2 = (.66)\ (4.6) = 3.0$

$x_3 = (.60)\ (2.4) = 1.4$

$x_4 = (.55)\ (2.4) = 1.3$

$x_{1\text{-hr.}} = \underline{9.2\text{ ppm}}$

(See Example 1 for details)

At R2 from Figures 6, 7 and 8

$x_1 = (.58)\ (10.4) = 6.0$

$x_2 = (.49)\ (10.4) = 5.1$

$x_3 = (.53)\ (2.5) = 1.3$

$x_4 = (.48)\ (2.5) = 1.2$

$x_{1\text{-hr.}} = \underline{13.6\text{ ppm}}$

(See Example 2 for details)

At R3 from Figures 9, 7 and 10

$x_5 = (.75)\ (14.5) = 10.9$

$x_6 = (.74)\ (2.6) = 1.9$

$x_{1\text{-hr.}} = \underline{12.8\text{ ppm}}$

(See Example 3 for details)

(3) Estimate 8-hour meteorological persistence factor using information in columns (13) - (16).

$$p = [\tfrac{3}{8}]\ (\tfrac{2000}{1600}) = 0.5 \text{ for points R1 and R2.} \qquad (1)$$

Note that information in columns (13) - (16) may frequently not be available. In such cases, a persistence factor of 0.6 may be assumed. A persistence factor of 0.6 is assumed for point R3.

(See Example 4 for details)

(4) Estimate 8-hr impact of nearby traffic at point R1, R2 and R3 using information in columns (8), (9), (11) and (12), and Figures 3, 5, 6, 7, 8, 9, and 10.

At R1: $x_1 = (.75)\ (2.5) = 1.9$

$x_2 = (.66)\ (2.5) = 1.7$

$x_3 = (.60)\ (2.5) = 1.5$

$x_4 = (.55)\ (2.5) = 1.4$

$x_{1\text{-hr.}} = 6.5$

$x_{8\text{-hr.}} = (.5)\ (6.5) = \underline{3.3\ \text{ppm}}$

At R2: $x_1 = (.58)\ (7.4) = 4.3$

$x_2 = (.49)\ (7.4) = 3.6$

$x_3 = (.53)\ (2.6) = 1.4$

$x_4 = (.48)\ (2.6) = 1.2$

$x_{1\text{-hr.}} = 10.5$

$x_{8\text{-hr.}} = (10.5)\ (.5) = \underline{5.3\ \text{ppm}}$

At R3: $x_5 = (.75)\ (6.1) = 4.6$

$x_6 = (.74)\ (2.1) = 1.6$

$x_{1\text{-hr.}} = 6.2$

$x_{8\text{-hr.}} = (6.2)\ (0.6) = \underline{3.7\ \text{ppm}}$

(See Example 4 for details)

(5) Estimate the maximum 1-hour and 8-hour ambient CO concentrations occurring at point R1, R2 and R3 taking into consideration cold temperature-cold start and emission control correction factors. Note that a correction factor for 1977 is used since this is the first year after the source starts operation.

Using the information in columns (1),(17), (18) and (19), the maximum 1- and 8-hour ambient concentrations at R1, R2 and R3 are estimated as follows:

At R1:

$\chi_{1\text{-hr}}\ (9.2)\ (.8)\ (.6) + (6)\ (.8) = 9.2 \approx \underline{9\text{ ppm}}$

$\chi_{8\text{-hr}} = (3.3)\ (.8)\ (.6) + (3)\ (.8) = 4.0 \approx \underline{4\text{ ppm}}$

At R2:

$\chi_{1\text{-hr}} = (13.6)\ (.8)\ (.6) + (6)\ (.8) = 11.3 \approx \underline{11\text{ ppm}}$

$\chi_{8\text{-hr}} = (5.3)\ (.8)\ (.6) + (3)\ (.8) = 4.9 \approx \underline{5\text{ ppm}}$

At R3:

$\chi_{1\text{-hr}} = (12.8)\ (.8)\ (1.7) + (11)\ (.8) = 26.2 \approx \underline{26\text{ ppm}}$

$\chi_{8\text{-hr}} = (3.7)\ (.8)\ (1.7) + (5)\ (.8) = 9.0 \approx \underline{9\text{ ppm}}$

(See Examples 7 and 8 for details.)

Example 11

(a) Purpose. The purpose of this example is to illustrate how the screening procedure can be extended to estimate a representative CO concentration along a sidewalk centerline.

(b) Problem. Suppose it is of interest to estimate the worst representative CO concentration at breathing height along a sidewalk's centerline which is 5 meters from curbside. The sidewalk is adjacent to a 2-lane road over a block which is 300 meters long (see sketch on the following page). The intersection at one end of the block (intersection 1) is signalized with G/Cy = 0.6 and a cycle length of 120 seconds. The other intersection (intersection 2) is non-signalized, with a STOP sign serving as the means of traffic control. Assume each lane is 5 m wide. The following traffic data are given:

$v_7 = 1000$ vph

$v_8 = 400$ vph

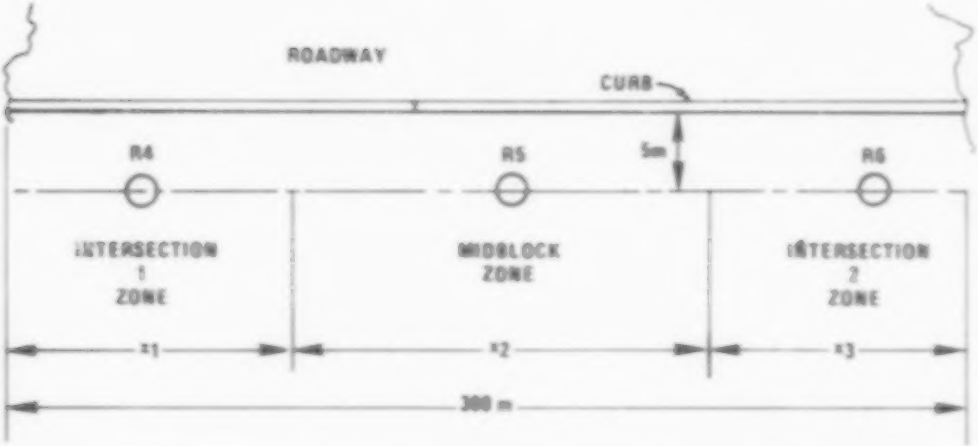
Non-signalized intersection capacity = 500 vph.

Assume midblock capacity is controlled by the intersection capacities so that

$c_7 \approx 1200$ vph

$c_8 \approx 500$ vph

What is the representative impact of the adjacent roadway on CO concentrations along the sidewalk centerline?


ROADWAY
CURB
R4
R5
R6
5m
INTERSECTION 1 ZONE
MIDBLOCK ZONE
INTERSECTION 2 ZONE
x1
x2
x3
300 m

(c) Solution.

(1) Divide block into three zones.

Zone 1 = signalized intersection zone.

Zone 2 = midblock zone.

Zone 3 = unsignalized intersection zone.

(2) Use Equation (7), Section 6.1 to estimate size of zone 1.

$$X_1 = \frac{1000\ (1 - 0.6)\ 8}{30} = 107 \text{ meters} \qquad (7)$$

(3) Use Equation (8), Section 6.1 to estimate size of zone 3.

$$X_3 = \left[\frac{400^2}{500\ (500 - 400)}\right] 8 = 26 \text{ meters} \qquad (8)$$

(4) Estimate midblock zone size.

$X_2 = 300 - 107 - 26 = 167$ meters

(Note that as congestion becomes greater, the block becomes increasingly dominated by the intersection zones.)

(5) Estimate maximum concentrations in each zone.

(a) For R4:

$\chi_7 = 15$ ppm (From Figure 6)

$\chi_8 = (2.5)\ (1.22) = 3.1$ ppm (From 25 mph curve Figures 7 and 8)

Therefore, $\chi_{R4} = 18.1$ ppm

(b) For R5:

$\chi_7 = 9.4$ ppm (From Figure 3)

$\chi_8 = (2.5)\ (1.22) = 3.1$ ppm (From Figures 3 and 5)

Therefore, $\chi_{R5} = 12.5$ ppm

(c) For R6:

$\chi_7 = 2.5$ ppm (From Figure 7)

$\chi_8 = (12.5)(1.22) = 15.3$ ppm (From Figures 9 and 10)

Therefore, $\chi_{R6} = 17.8$ ppm

(6) Estimate weighted average of zonal concentrations.

$$\chi_{Rep} = \frac{(18.1)(107) + (12.5)(167) + (17.8)(26)}{300}$$

$$\chi_{Rep} = 15.0 \approx \underline{15\ \text{ppm}}$$

The analysis can be extended to estimate 8-hour concentrations. The procedure would be to reidentify the zones estimated in steps (1)-(4) above using the hourly average traffic demands for the 8-hour period of interest. Next, procedures outlined in Section 4.2 and illustrated in Example 4 may be used to estimate the maximum CO impacts in each zone. Finally, the weighted average of the zonal impacts is estimated as in step (6) above.

4.7 Summary of the Screening Procedure

Figure 11 is a flow chart illustrating the screening procedure for the review of the impact of a proposed indirect source on ambient carbon monoxide concentrations. The screening technique proceeds as follows:

1. Obtain and review information received from the applicant concerning projected 1- and 8-hour traffic demands and capacities at locations in the vicinity of identified key receptor points.

2. Assuming there is no continuously operating representative CO monitoring site in the vicinity of the proposed source, obtain background concentration data from the applicant.

3. Seasonally adjust background data as described in Section 4.3.1 and in Example 5, Section 4.6. If the background monitoring site is within 100 meters of a major existing road being evaluated, proceed in "calibrating" the curves in Figures 2-10 and estimating 1-hour and (for non-event sources) 8-hour ambient CO concentrations as described in Section 4.3.2 and in Example 6 in Section 4.6. Preferably, however, the background data should be obtained at a representative site at least 100 meters from any major existing road. If this is the case, proceed as described in the remaining steps.

4. Estimate the impact of nearby traffic lanes on 1-hour CO concentrations at selected receptor points. Estimates are made using Figures 2-10 as described in Section 4.1 and in Examples 1-3 in Section 4.6. If the source is an event-oriented one, such as a

Figure 11. Summary of the Indirect Source Screening Procedure

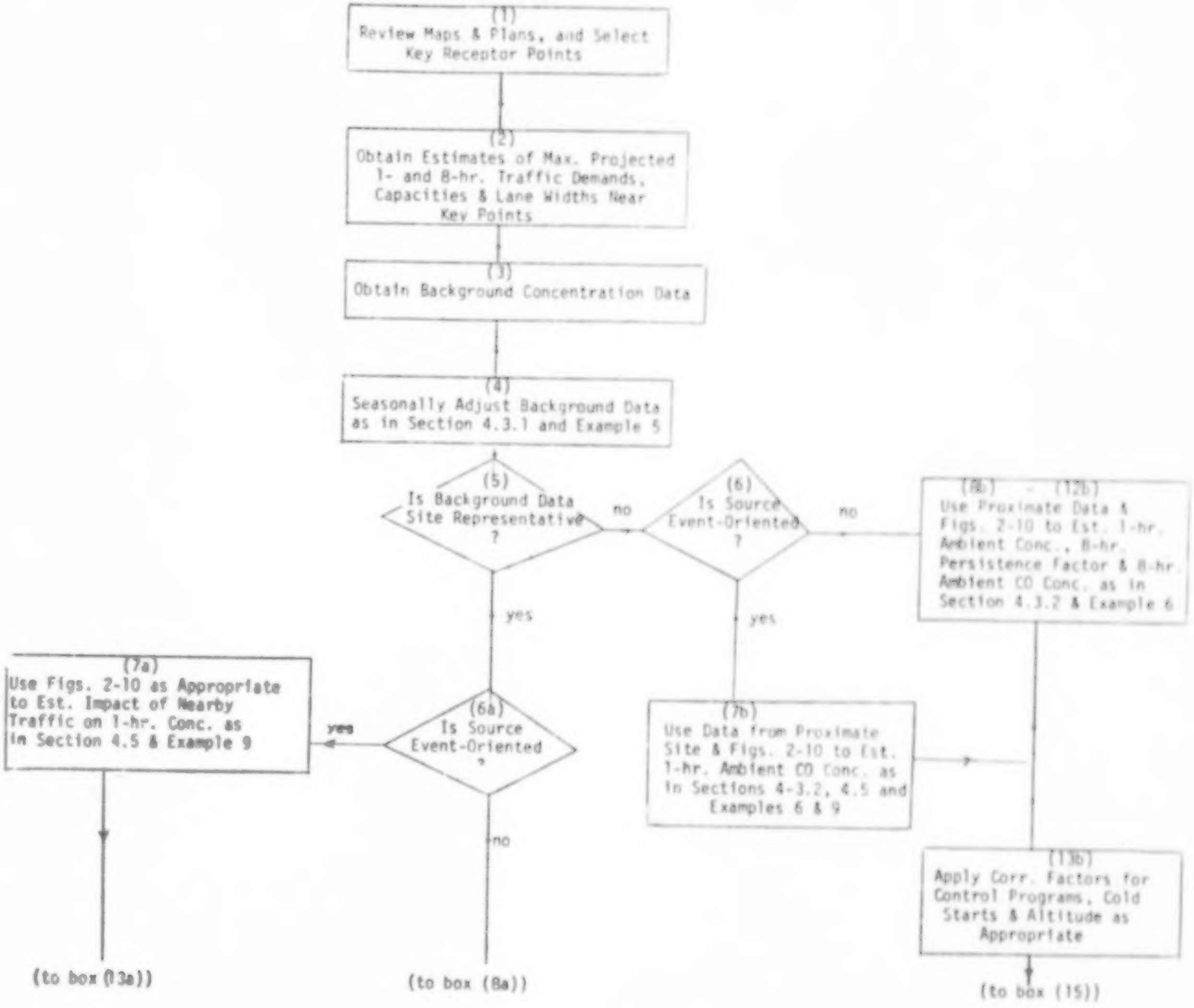

(1)
Review Maps & Plans, and Select Key Receptor Points
(2)
Obtain Estimates of Max. Projected 1- and 8-hr. Traffic Demands, Capacities & Lane Widths Near Key Points
(3)
Obtain Background Concentration Data
(4)
Seasonally Adjust Background Data as in Section 4.3.1 and Example 5
(5)
Is Background Data Site Representative ?
no
yes
(6)
Is Source Event-Oriented ?
no
yes
(8b) - (12b)
Use Proximate Data & Figs. 2-10 to Est. 1-hr. Ambient Conc., 8-hr. Persistence Factor & 8-hr. Ambient CO Conc. as in Section 4.3.2 & Example 6
(7b)
Use Data from Proximate Site & Figs. 2-10 to Est. 1-hr. Ambient CO Conc. as in Sections 4-3.2, 4.5 and Examples 6 & 9
(13b)
Apply Corr. Factors for Control Programs, Cold Starts & Altitude as Appropriate
(to box (15))
(6a)
Is Source Event-Oriented ?
yes
no
(7a)
Use Figs. 2-10 as Appropriate to Est. Impact of Nearby Traffic on 1-hr. Conc. as in Section 4.5 & Example 9
(to box (13a))
(to box (8a))

Figure 11 (continued)

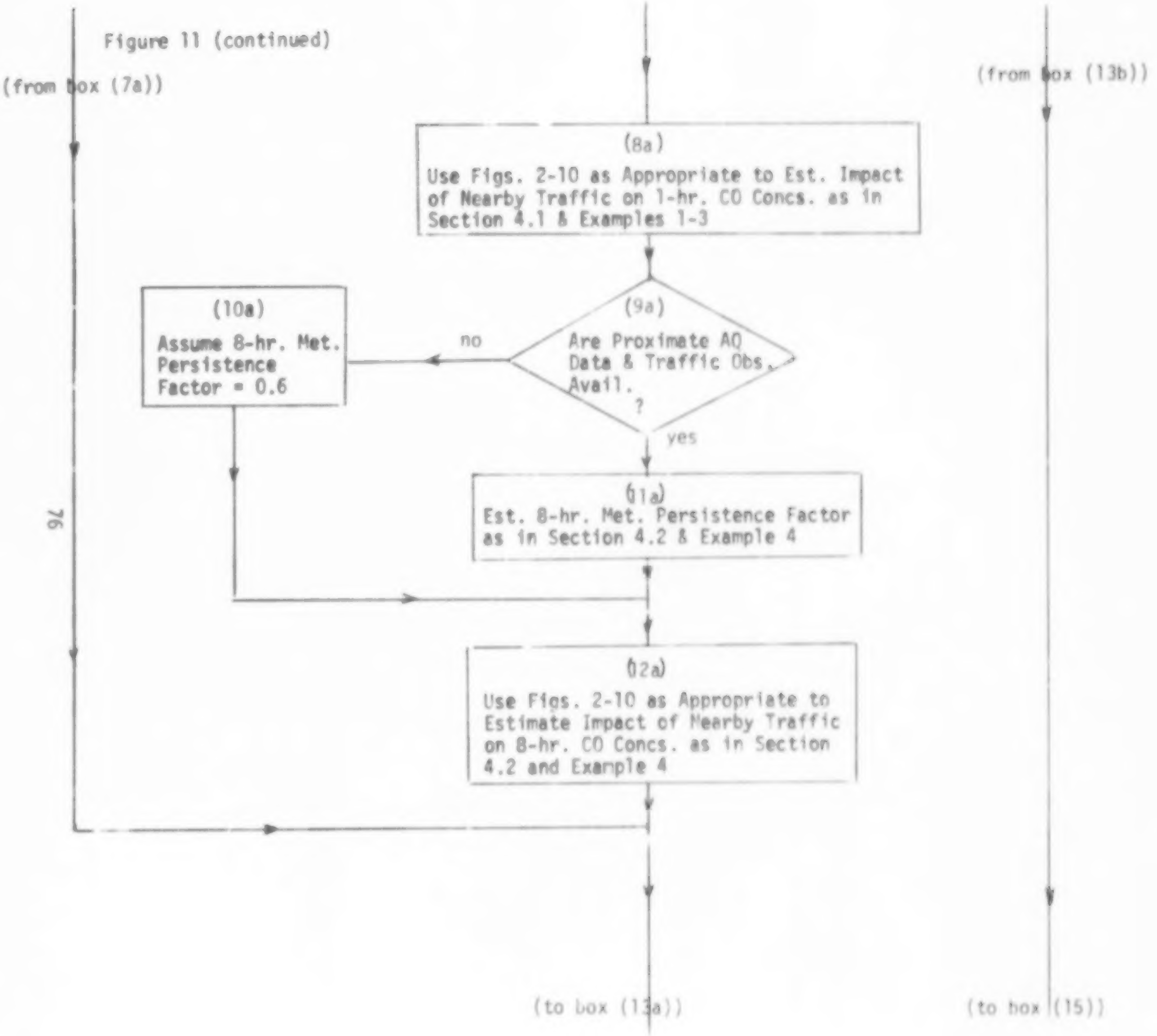
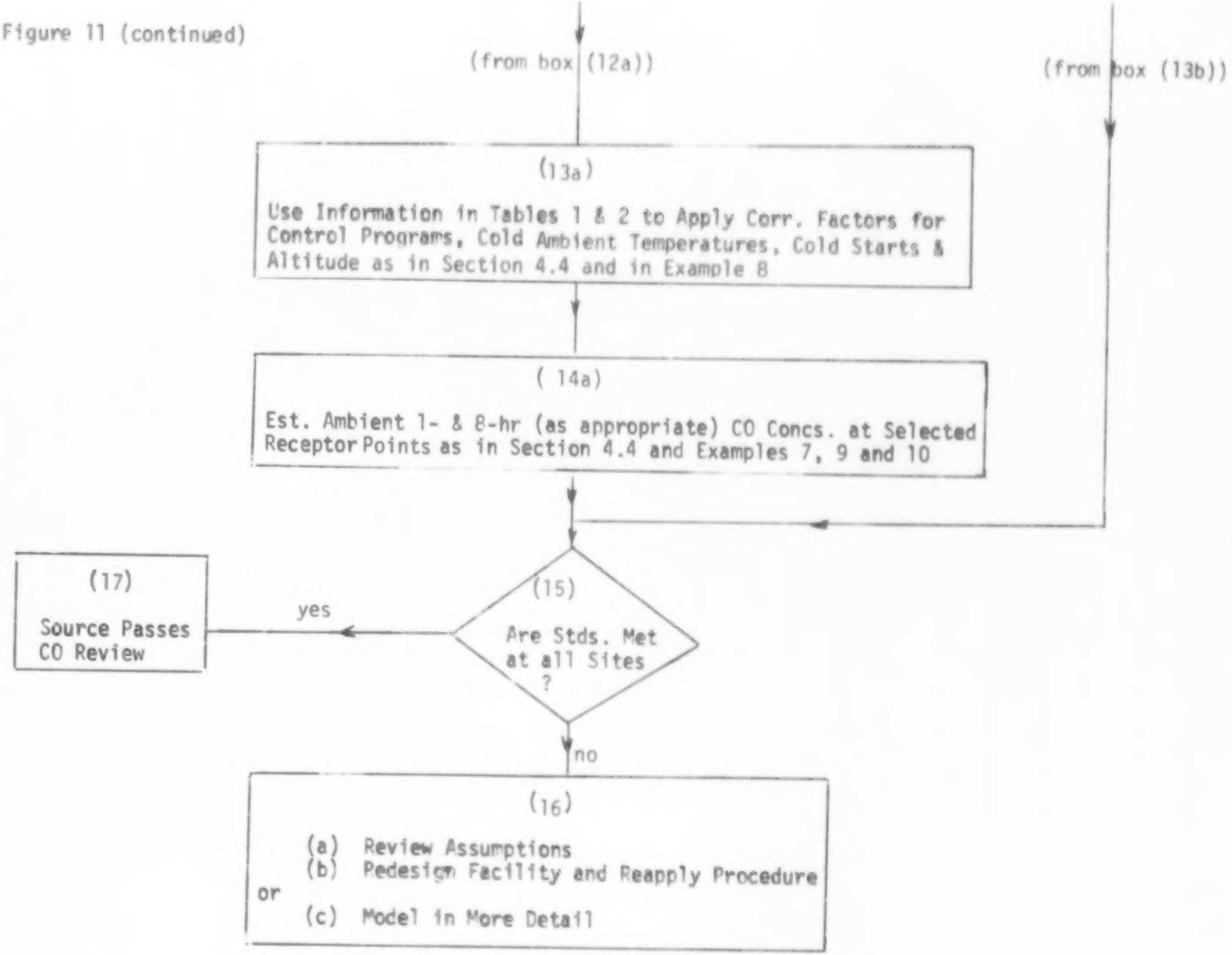

(from box (7a))
(8a)
Use Figs. 2-10 as Appropriate to Est. Impact of Nearby Traffic on 1-hr. CO Concs. as in Section 4.1 & Examples 1-3
(9a)
Are Proximate AQ Data & Traffic Obs. Avail. ?
no
yes
(10a)
Assume 8-hr. Met. Persistence Factor = 0.6
(11a)
Est. 8-hr. Met. Persistence Factor as in Section 4.2 & Example 4
(12a)
Use Figs. 2-10 as Appropriate to Estimate Impact of Nearby Traffic on 8-hr. CO Concs. as in Section 4.2 and Example 4
(to box (13a))
(from box (13b))
(to box (15))

Figure 11 (continued)


(from box (12a))
(from box (13b))
(13a)
Use Information in Tables 1 & 2 to Apply Corr. Factors for Control Programs, Cold Ambient Temperatures, Cold Starts & Altitude as in Section 4.4 and in Example 8
(14a)
Est. Ambient 1- & 8-hr (as appropriate) CO Concs. at Selected Receptor Points as in Section 4.4 and Examples 7, 9 and 10
(15)
Are Stds. Met at all Sites ?
yes
no
(17)
Source Passes CO Review
(16)
(a) Review Assumptions
(b) Pedesign Facility and Reapply Procedure
or
(c) Model in More Detail

sports stadium, revise the analysis as described in Section 4.5 and as shown in Example 9 in Section 4.6.

5. If the source is not an event-oriented one, derive an 8-hour meteorological persistence factor. Use this factor with the projected 8-hour traffic demands, and apply Figures 2-10 to estimate the impact of nearby traffic on ambient 8-hour CO concentrations at the selected receptor points. This procedure is described in Example 5 in Section 4.6.

6. Apply cold temperature-cold start and altitude correction factors (obtained from Tables 1 and 2) to the estimated impacts of nearby traffic, as needed. Apply a correction factor reflecting the status of emission control programs (as appropriate) to both the estimated impact of nearby traffic and the seasonally-adjusted observed background concentration. This procedure is described in Section 4.4 and in Example 8 in Section 4.6.

7. Add the estimated impact of nearby traffic to the estimated background concentration to obtain estimated 1- and 8-hour ambient CO concentrations at all receptor points of interest. This procedure is described in Section 4.4 and in Examples 7, 9 and 10 in Section 4.6.

8. If the conservative screening procedure indicates the National Ambient Air Quality Standards will be met at all selected receptor points, it may be assumed that the proposed source will not pose a threat to the ambient CO standards. If the NAAQS is exceeded at one or more of the selected receptor points, the applicability of

the assumptions used in deriving the screening procedure should be reviewed. These assumptions are described in Section 6.0. Depending on the outcome of this review,

(1) The source could be redesigned in some manner and the screening procedure could be reapplied, or

(2) A detailed modeling analysis, using meteorological, emission and traffic assumptions specifically applicable for the source under consideration, could be initiated.

5.0 ECONOMIC AND DESIGN CONSIDERATIONS

There are three types of costs associated with indirect source review. These are:

(1) Cost of data acquisition and application preparation;

(2) Time-related costs, and

(3) Cost of design changes necessitated by indirect source review.

Information concerning each of these costs has been compiled in a report on the economic and land use impact of the indirect source regulations which has been prepared for EPA.[28] It is strongly recommended that indirect source reviewing agencies become familiar with the contents of this report and the insight it provides concerning basic concepts and principles governing the real estate development industry.

5.1 Data Acquisition and Application Costs

The following estimates are provided so that reviewer and applicant alike may have an indication of the scope of effort envisioned for various levels of analysis.

Effort	Approximate Cost
1. Obtaining traffic data not already available, filling out the application form and applying the screening procedure described in Section 4.0 without air quality monitoring data.	$3000.
2. Obtaining and reducing 14 days of air quality monitoring data collected at one site.	$6000.
3. Performing a complete modeling analysis including the costs of monitoring meteorological, air quality and traffic data at several locations, and computer costs required to use observed data in an atmospheric dispersion model.[28]	$35,000-$50,000.

5.2 Time-Related Costs

These costs accrue from the delay and uncertainty which may be introduced by regulatory programs or other factors such as bad weather, labor problems or shortages of key construction materials. Time-related costs can, in some cases, greatly exceed even the costs of a complete modeling analysis. For example, in six case studies examined in the previously cited report,[28] estimated time-related costs associated with an assumed three month delay in construction for large projects (i.e., $25-125 million) exceeded the cost of a complete modeling analysis by an order of magnitude. Of particular importance is the developer's own capital ("front-end money") which must be invested before a loan can be secured from a savings and loan institution. The ease with which such a loan can be obtained (so that the developer's money can be reinvested) depends upon, among other things, amount and length of uncertainty associated with indirect source review. Degree of uncertainty is particularly crucial during times when credit is "tight." Time-related costs are further aggravated by inflation, high interest rates once a loan is secured and shortages in building materials resulting in less flexibility in delivery dates. It should be readily apparent, from the brief preceding discussion, why it is essential to minimize delays occasioned by the processing of indirect source review applications. To minimize such delays, indirect source reviewing agencies should make every effort to develop close working relationships with other agencies (e.g., State and local highway departments) which may become involved in the review procedure.

5.3 Design Changes

The costs associated with changes in design necessitated by analysis of a proposed source's impact on ambient air quality depends on: (1) the degree of the problem identified in the analysis, and (2) the measures selected to eliminate the unacceptable impact on air quality. Obviously, the first consideration is highly variable, resulting in costs ranging from zero all the way up to prohibitive levels which would make the project infeasible. Essentially, design changes involve measures reducing or redistributing traffic demand during critical periods, or measures increasing the capacity of the proposed facility or surrounding road network to accommodate traffic.

Alterations in traffic demand and/or capacity could be effected by changing certain operating procedures (e.g., providing for traffic supervision during peak use periods, altering direction of flow, etc.) or design features at the source or in its vicinity. There are a number of ways in which design and/or operating changes could be made. The following is a list and description of some important determinants of traffic demand and capacity which might be altered in order to improve traffic flow and thereby reduce the threat to CO standards.

5.3.1 Traffic Demand Determinants

Existing and future through traffic demand on roadways adjacent to or within an indirect source are determined by two factors:

(a) The existing future area wide arterial and/or expressway system, and

(b) The potential for activity growth in the vicinity of the site.

Traffic demand generated directly by the source itself is dependent upon the following design and operational parameters:

(a) Size and nature of attractions (e. g., tenant mix for shopping centers, type of activities offered at recreational areas, etc.);

(b) Operation of the source (e. g., opening times, special event days, time and scheduling of special activities such as sales or sporting events, employee working schedules);

(c) Split of transportation modes (e. g., bus, rail, pedestrian, automobile, etc.).

The traffic distribution to the source and using any single nearby roadway is determined by:

(a) Geographical location of the source with respect to trade area population and area road network;

(b) Predominating levels of service on the roadways comprising the road net;

(c) Number and design of entrances serving the source.

5.3.2 Traffic Capacity Determinants

Traffic capacity at entrance/exit gates and at at-grade intersections may be altered by changing one or several of the following factors:

(a) Intersection Geometrics

(1) Turning radii.

(2) Number of lanes.

(3) Lane widths.

(4) Presence of turning lanes.

(5) Storage distances for turning lanes.

(6) Presence of parked vehicles.

(7) Lateral clearance.

(8) Grade.

(9) One-way or two-way streets.

(b) Traffic Controls

(1) Type of control (e.g., traffic signal, stop sign, yield sign, policeman, etc.).

(2) Operation of controls. These considerations include signal phasing, green time to signal cycle ratio, signal cycle length, signal actuation progression (i.e., how well successive signals are coordinated) and presence of right- and/or left-turn signals.

(c) Nature of Traffic Demand

(1) Number of trucks.

(2) Number of buses.

(3) Number of turning vehicles (left and right) vs. number of through vehicles.

(4) Surging effects (peak hour factors, land factors) and their impact on congestion on successive road segments.

(d) Environmental Factors

(1) Population in area (i.e., is area urban, rural, etc?).

(2) Location (central business district, fringe area, outlying business district, residential, rural).

(e) Entrance/Exit Gate Controls

(1) Manual vs. automated issuance of parking tickets (with or without parking gate controls).

(2) Manual vs. full or semi-automated collection of parking fees at exit gates.

(3) Self-service vs. attendant method of parking operation.

(f) Vehicle Movement/Circulation Inside Indirect Sources

(1) Type of parking facility (i.e., short term, long term, mix of both, etc.).

(2) Internal functional efficiency of parking facility (i.e., circulation pattern, one- vs. two-way movement, parking stall sizes and layout, directional and informational signing, pre- vs. exit-cashiering, etc.).

6.0 ASSUMPTIONS USED IN THE SCREENING PROCEDURE

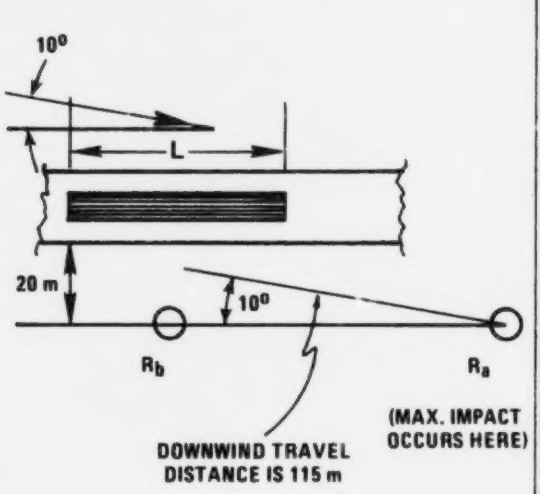
In order to develop the reasonably simple methodology relating traffic demand, capacity and demand-capacity ratios to CO concentrations, it has been necessary to sacrifice flexibility in evaluating a source's impact by making a number of assumptions. These assumptions are enumerated in this section. Since it is necessary that the screening procedure provides reasonable assurance that the NAAQS are protected, most of the assumptions are conservative ones. In cases where it is relatively easy to adapt the procedure presented in Section 4.0 to different assumptions, this is so indicated. Where different assumptions may not be so readily incorporated in the screening procedure, it may be necessary to refer to Appendix H and the appropriate one(s) of Appendices A-G to estimate the impact of a proposed source on ambient air quality.

6.1 Meteorological Assumptions

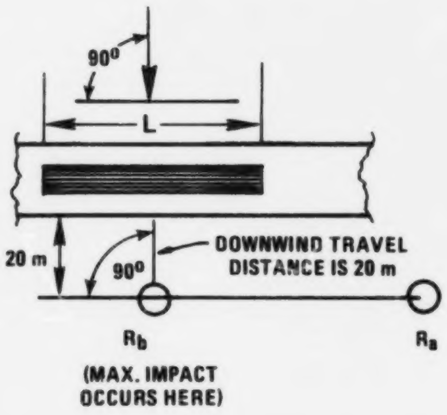
A. Wind speed--A steady wind speed of 1 m/sec was assumed in deriving Figures 2-10. Estimates of 1-hour CO concentrations can be adapted for different wind speeds by dividing the concentration obtained with the figures by the wind speed. For example, if a 1-hour concentration of 10 ppm were estimated and the wind speed were 2 m/sec, the 1-hour concentration estimate would be revised to 5 ppm. The adaptation of the screening procedure to account for wind speeds exceeding 2 m/sec can only be extended to 8-hour concentrations if a persistence factor is derived specifically for observations occurring near the proposed source site. These observations must reflect variations between observed 1- and 8-hour CO concentrations which occur when the wind speed during the hour in which the peak 1-hour concentration is observed corresponds closely to that assumed in the methodology. Since persistence is not independent of wind speed, the arbitrary value of "0.6" cannot be used unless verified directly by observation for higher 1-hour average wind speeds near the site.

B. Wind direction--A wind direction making an angle of 10° with the roadway was assumed in deriving the free-flow curves in Figures 2, 3, 4, 7 and 9. For a long line source of pollution, this wind angle is believed to be among those resulting in highest concentrations at nearby receptors. The curves in Figure 6 and the queuing curve in Figure 9 are the result of a series of analyses of concentrations occurring with different wind angles. This approach was necessitated, because the impact of queues at intersections occurs over a relatively short distance and is best represented by a finite line source. Therefore, "edge effects," resulting in the dilution of emissions in the finite line source with relatively clean air, can play an important role in determining CO concentrations at receptors located near a roadway. The importance of edge effects depends on the length of the queue and the downwind travel distance between the roadway and the receptor point. The downwind travel distance, in turn, depends on the wind angle and perpendicular distance between the roadway and receptor point. For a given perpendicular distance, the smaller the wind angle, the greater the travel distance. This concept is sketched below for receptor points located a perpendicular distance of 20 m from the road, wind angles of 10° and 90° and a queue length of "L."

CASE (A) $\theta = 10^\circ$


10°
L
20 m
10°
R_b
R_a
(MAX. IMPACT OCCURS HERE)
DOWNWIND TRAVEL DISTANCE IS 115 m

CASE (B) $\theta = 90^\circ$


90°
L
20 m
90°
DOWNWIND TRAVEL DISTANCE IS 20 m
R_b
R_a
(MAX. IMPACT OCCURS HERE)

An adaptation of the "Red Time Formula" was used in estimating the average queue length resulting during the red phase at signalized intersections.[21]

$$L = \frac{v(1 - G/Cy)D}{CPH} \tag{7}$$

where L = queue length, meters;

v = traffic demand, vph;

G/Cy = green time to signal cycle ratio, dimensionless;

D = spacing between successive vehicle tailpipes in the queue, assumed to be 8 m/veh;

CPH = number of signal cycles per hour.

An adaptation of a formula from classical queuing theory was used for non-signalized intersections.[29]

$$L = \left[\frac{v^2}{c(c-v)}\right] D \tag{8}$$

where c = capacity, vph, and the other symbols are as defined for Equation (7).

Equations (7) and (8) indicate that for low demand-capacity ratios and demands, the average queue length (L) is short. Under such circumstances, edge effects become important even with very short downwind travel distances. For greater downwind travel distances, the edge effects become so great that the impact of the queue is negligible.

Thus, there is a trade-off between the (a) high concentrations resulting with small wind angles but having relatively great edge effects, and (b) low concentrations accompanying large wind angles but having relatively minor edge effects. In order to provide a conservative evaluation of the impact of queues (represented as finite line sources), a wind angle of 90° was assumed for queue lengths of 25 meters or less, and a series of wind angles decreasing from 20° to 10° were assumed for increasing queue lengths greater than 25 meters.

C. Atmospheric Stability--Pasquill-Gifford Stability Class D is assumed in the line source model (HIWAY)[30] used to derive the curves in Figures 2 - 10. A value of 1.5 meters is used for the initial vertical plume speed parameter (σ_{zo}) in HIWAY. Assumption of the Class D Pasquill-Gifford stability class as a worst case was made because the indirect source-parking management review programs are likely to focus on urbanized areas. Increased atmospheric turbulence, attributable to a greater degree of surface roughness and increased convective turbulence in such areas, are likely to make plume spread predictions based on Pasquill-Gifford stability classifications (which are based on observations in open country) overly conservative. A dispersion study conducted in St. Louis[31] indicated that for downwind distances ranging from about 1000-10,000 meters, observed plume spread occurring at night with meteorological conditions indicative of Class E and F stability in rural areas corresponded approximately with that estimated using Pasquill-Gifford Stability Class D stability. The previously referenced study[31] indicated a tendency for the Pasquill-Gifford plume spread curves to become increasingly conservative as downwind travel distances decreased. Therefore, in general, an assumption of Pasquill-Gifford Stability Class D is believed to be conservative for most areas in which indirect source review will occur. It should be emphasized, however, that after appropriate data are reviewed for a proposed site by a trained meteorologist, more or less stable conditions than Pasquill-Gifford Class D may be appropriate.

The value of σ_{zo} = 1.5 meters, used in the EPA HIWAY model, is representative of the lower range of values observed from a limited data base.[30] Subsequent studies conducted in the vicinity of an expressway[32] and in the vicinity of a residential street with trees on either side[33] have indicated greater vertical plume spread immediately downwind from a highway which may be generated by vehicular motion (at the expressway) or by surface roughness (at the residential street). This implies in some cases, larger σ_z values may be appropriate in the immediate vicinity of roadways than are currently used in the HIWAY Gaussian line source model. On the other hand, however, the σ_{zo} value used in HIWAY does have an empirical basis, and the model was able to simulate

CO concentrations observed in the vicinity of a suburban intersection quite well.[21] The data which have been reported to date are not believed sufficient to warrant revising the assumption about σ_{zo} in the HIWAY model. On the basis of the limited data available at the present time, however, there are indications that the assumption of $\sigma_{zo} = 1.5$ meters is conservative.

D. Persistence of Constant Meteorological Conditions--The relationships between traffic and nearby CO concentrations depicted in Figures 2-10 are based on the assumption that the unfavorable meteorological conditions described above will persist for at least an hour during periods in which the source will be utilized at peak levels. The persistence factor which should be used in estimating 8-hour concentrations is an acknowledgment that such conditions are not likely to persist for 8 hours. The figure "0.6," which is suggested for use if it is infeasible to derive a persistence factor reflecting local meteorological variability, is an empirical factor based on a limited data base.[20] The value was derived by noting the ratio of 8-hour to 1-hour maximum concentrations at a receptor in the vicinity of the major entrance/exit gate to a regional shopping center on days in which the hourly average wind speed accompanying the maximum observed 1-hour concentration was less than 2 m/sec. Next, the corresponding traffic volume flow rates (in veh/hr) were recorded for the selected 8-hour and 1-hour periods and factored out. After account was taken of differences in traffic demand, the resulting ratio between the 8- and 1-hour maximum CO concentrations at the exit gate was assumed to be attributable to meteorological changes over the 8-hour period. The largest observed ratio was about "0.6."

6.2 Emission Assumptions

A. Free-flow Line Source Emission Intensity--Equation (9) was used to estimate emission intensity for an infinitely long line source of freely flowing traffic (used in deriving the "free-flow" curves in Figures 2-4 and 9).

$$q_{ij} = (1.036 \times 10^{-5})\,(EF)_{ij}\,v_{ij}/S_{ij} \qquad (9)$$

where q_{ij} = line source emission intensity at exit gate (road segment) i, lane j, gm/sec-m

v_{ij} = traffic volume demand at gate (road segment) i, lane j, vph

S_{ij} = vehicle operating speeds at gate (road segment) i, lane j, mph

$(EF)_{ij}$ = speed-dependent CO emission factor for vehicles operating at S_{ij} in lane j at gate (road segment) i, gm/min-veh

(1.036×10^{-5}) = conversion factor from $\frac{gm}{min\text{-}mi}$ to gm/sec-m

B. Line Source Emission Intensity Arising from Queues

1. Signalized Intersection Approaches. The methodology used at these locations is similar to that used in Reference 21.

Emissions arising from queues are regarded as the sum of three components: a component attributable to cruising vehicles, a component resulting from accelerating and decelerating vehicles, and a component resulting from idling vehicles. The first component is assumed to occur over an infinitely long line source. The second and third components are manifested over a finite line source whose length is estimated using Equation (7). Equation (9) is used to estimate the emission intensity which would result if all vehicles comprising the traffic demand were cruising past the intersection at a given intersection approach speed. Appropriate intersection approach speeds were estimated using empirical relationships between midblock volume-capacity ratios and vehicle operating speeds on major streets.[22] Midblock capacity was assumed to be (2000)(G/Cy)(# of Lanes). The second and third components are regarded as "excess emissions" occurring over the finite queue length as a result of acceleration/deceleration and idling. The intensity of the acceleration/deceleration component is:

$$q_{ij} = \left[\frac{\overline{(EF)}_{ij}}{60\ D}\right] (1 - G/Cy) \qquad (10)$$

where q_{ij} = line source emission intensity gm/sec-m;

D = spacing between successive vehicle tailpipes, assumed to be 8m/veh;

$\overline{(EF)}_{ij}$ = average emission factor for an accelerating and decelerating vehicle over the estimated queue length, gm/min-veh;

G/Cy = green time to signal cycle ratio, dimensionless;

$\frac{1}{60}$ = conversion factor from min^{-1} to sec^{-1}.

The intensity of the idling component is:

$$q_{ij} = \frac{(0.5)\ (EF)_{ij}\ (1 - G/Cy)}{60D} \qquad (11)$$

where $(EF)_{ij}$ = the CO emission factor for idling vehicles, gm/min-veh

G/Cy = green time to signal cycle ratio, dimensionless

D = spacing between successive vehicle tailpipes, assumed to be 8m/veh

$\frac{1}{60}$ = conversion factor from min^{-1} to sec^{-1}

0.5 = constant denoting that the average vehicle in the queue is only there for 1/2 the signal's red phase, dimensionless.

2. Non-Signalized Intersection Approach. The queuing curve in Figure 9 was obtained by assuming that, on the average over the entire period of interest, the average queue length may be estimated using Equation (8). The intensity of this finite line source is:

$$q_{ij} = \frac{(EF)_{ij}}{60D} \qquad (12)$$

where $(EF)_{ij}$ = average trip emission factor for vehicle speeds about 0 mph; gm/min-veh.

The other terms are as defined in Equation (11). Note that $(EF)_{ij}$ in Equation (12) is not the same as the idle emission factor used in Equation (11). The emission factor in Equation (12) is more appropriate for stop-and-start traffic likely to be found in very congested locations or upstream from a toll booth or "STOP" sign.

C. Emission Factor Assumptions--The CO emission factors assumed in deriving Figures 2-4, 9 and 10 were obtained by using the emission factor information for a national average mix of vehicles (by model year) derived from Supplement Number 5 to AP-42 for the calender year 1975 and speed correction factors from the same reference.[26] It is assumed that 20 percent of these vehicles are operating from a cold start and approximately 88 percent of the vehicle mileage is attributable to light-duty vehicles and 12 percent is the result of light-duty trucks. Emission factors in the correct units (gm/min-veh) were obtained using Equation (13).

$$EF = \frac{(ef)\ (c(s))\ (\text{vehicle speed})}{60} \qquad (13)$$

where ef = composite emission factor for calendar year 1975, gm/mi-veh

c(s) = speed correction factor from Supplement Number 5 to AP-42, dimensionless

vehicle speed = miles/hour

EF = emission factor, gm/min-veh

1/60 = conversion factor from hr^{-1} to min^{-1}

The emission factors obtained using Equation (13) appear in Tables 3-5 in Section 6.3. Emission factors (gm/min-veh) for vehicle speeds less than 5 mph were estimated by extrapolating a curve plotting EF vs. vehicle speed. The emission factor corresponding to an average trip speed of 0 mph using this procedure was 20 gm/min-veh. This factor was assumed in deriving the queuing curve in Figure 9.

The emission factors used in deriving Figures 6 and 7 were estimated using the Automobile Exhaust Emission Modal Analysis Model.[34] Combinations of vehicle operating modes used in the model were similar to observed traffic in the vicinity of a signalized intersection.[21] Since the Automobile Exhaust Emission Modal Analysis Model assumes that there are no vehicles operating from a cold start, a correction factor was applied to the estimates obtained with the model to reflect an assumption of 20 percent cold starts. This was done so that all the curves in Section 4.1 reflect consistent assumptions about the percentage of cold starts. The ambient temperature was assumed to range from 68°F-86°F in deriving the curves in Section 4.1.

Correction factors for cold starts and cold temperatures, appearing in Table 1, were obtained using procedures outlined in Supplement Number 5 to AP-42.[26] These procedures are, in turn, based on published data[35,36] reflecting the impact of differing ambient temperatures on emissions from cold and warmed-up vehicles using the 1975 Federal Test Procedure.[27] A cold soak period of 4 hours is suggested as a guide to ascertain whether cold operation of vehicles is significant.[26] Data concerning this question are not extensive at present. Other data[37,38] indicate that increased CO emissions attributable to cold starting vehicles in cold temperatures essentially all occur within the first 4 minutes of operation.

The correction factors for national emission control programs and altitude were obtained by first estimating CO emission factors for a typical nationwide mix (by model year) of vehicles for a mix in Denver and for a mix in California for each of the indicated calendar years. These factors were obtained by following the procedures recommended in Supplement Number 5 to AP-42.[26] The emission factors thus obtained were divided by the factor 55 gm/mi-veh, considered appropriate for a national average mix of vehicles in 1975 (composed of 88 percent light-duty vehicles and 12 percent light-duty trucks) to obtain the correction factors in Table 2.

6.3 Traffic Assumptions

In estimating the emissions from free-flowing traffic, it is necessary to assume values for representative vehicle operating speeds. Relationships between volume-capacity ratios and operating speeds on various types of roadways with specified average highway speeds can be estimated from the Highway Research Board's 1965 Highway Capacity Manual[22] providing it is assumed that traffic on the roadway is being accommodated at the maximum level of service consistent with the indicated v/c ratio. This procedure was followed in deriving Figure 2 for freeways and expressways and Figure 3 for major streets. Actual observations of speed-volume relationships for a given road under review would, of course, be preferable. For the free-flow curves, it was assumed that demand-capacity ratios were identical with volume-capacity ratios. This assumption implies that, under free-flow conditions, traffic is moving at the maximum level of service consistent with the specified volume-capacity ratio. Thus, it is possible to estimate operating speed on a roadway given the demand-capacity ratio. The combinations of operating speeds and demand-capacity ratios used for arterial streets and expressways, along with the corresponding levels of service and CO emission factors, appear in Tables 3 and 4.

It is not possible to relate operating speeds to volume-capacity ratios for traffic lanes within indirect sources with the given state of the art. It has been noted at a regional shopping center[20] that vehicle speeds average from 11-15 mph with little congestion. These average speeds included time spent stopping at signalized exit/entrance gates. Since it was reasonably consistent with observations, a speed of 15 mph was assumed in deriving the free-flow curves in Figure 4. The resulting CO emission factor used in deriving the free-flow curves in Figure 4 is presented in Table 5.

In deriving and using Figures 6-8 to estimate the impact of traffic at signalized intersections, assumptions concerning the green time to signal cycle ratio, signal cycle length and approach speeds have been made. If detailed information concerning the green time to signal cycle ratio and the degree of signal progression between successive signals is not known but it is known that the approach is on a major street, a G/Cy = 0.6 is suggested for use. The rationale for this is that the indirect source review will focus on times and locations where projected traffic demand is greatest. A traffic-actuated signal apportions green time according to traffic demand; so it is reasonable to assume that more green time will be available to the intersection

Table 3. ASSUMED OPERATING SPEEDS, LEVELS OF SERVICE AND DEMAND-CAPACITY RATIOS FOR MAJOR STREETS AND CORRESPONDING EMISSION FACTORS FOR FREE FLOW CONDITIONS

Assumed operating speed(mph)	Demand-capacity ratio	Level of Service	CO emission factor, gm/min-veh	Description
30	$\leq$ 0.60	A	17.2	Completely free flow
25	0.70	B	17.6	Stable flow (slight delay)
20	0.80	C	18.1	Stable flow (acceptable delay)
15	0.90	D	18.6	Approaching unstable flow (tolerable delay)
15	1.00	E	18.6	Unstable flow (congestion, intolerable delay)

Table 4. ASSUMED OPERATING SPEEDS, LEVELS OF SERVICE AND DEMAND-CAPACITY RATIOS FOR URBAN EXPRESSWAYS* AND CORRESPONDING EMISSION FACTORS FOR FREE FLOW CONDITIONS

Assumed operating speed (MPH)	Demand-capacity ratio	Level of Service	CO Emission factor gm/min-veh	Description
57	0.1	A	16.0	Completely free flow
55	0.2	A	16.0	Completely free flow
53	0.3	A	16.1	Completely free flow
50	0.4	A	16.2	Completely free flow
47	0.5	B	16.3	Stable flow (upper speed range)
45	0.6	C	16.3	Stable flow
42	0.7	C	16.4	Stable flow
40	0.8	C	16.5	Stable flow
37	0.9	D	16.6	Approaching unstable flow
30	1.0	E	17.2	Unstable flow

*Average highway speed assumed to be 60 mph

Table 5. ASSUMED OPERATING SPEEDS AND DEMAND-CAPACITY RATIOS FOR TRAFFIC LANES WITHIN INDIRECT SOURCES AND CORRESPONDING EMISSION FACTORS FOR FREE FLOW CONDITIONS

Assumed operating speed (mph)	Demand-capacity ratio	CO Emission factor, gm/min-veh
15	0 - 1.0	18.6

leg having the heaviest demand. For a major street, it is unlikely that the intersecting road will have as great a demand as the approach being reviewed. In addition, any kind of coordinated signal progression among signals with fixed cycles would exert the same impact on queue lengths and emissions as an increased G/Cy (i.e., fewer vehicles would arrive during the red phase). A more conservative G/Cy ratio of 0.5 is suggested for an approach on a local street or at an exit to an indirect source. In such cases it is possible that the traffic demand on the intersecting road (which could be a major street) may be as great as that on the local street or exit lanes, even during hours of peak demand on the smaller streets, and well-coordinated signal progression may be less likely.

For most demands, a signal cycle length of 120 seconds was used in deriving the curves in Figure 6. This number represents a value at the upper range of signal cycle lengths found at fixed-time signals, and about in the middle of the range commonly found at traffic-actuated signals on arterial roads.[39] Near the highest volume theoretically possible for a signalized intersection (estimated by multiplying a nominal lane capacity of 2000 vph by the green time to signal cycle ratio), a cycle length of 180 seconds was assumed. This value is representative of the upper range of cycle lengths for traffic-actuated signals. Longer-than-average cycle lengths were used, because they are most likely to occur with higher traffic demands.[22] In addition, the impact of queuing appears to be greater with longer cycle lengths.

A third assumption concerning approach speed is needed if it is not feasible to determine volume-capacity ratio at midblock. The suggestion to use 30 mph for major streets is based on speed limitations which may frequently prevail on such streets and the wide range of v/c ratio for which this speed is assumed in Table 3. The suggestion to assume a cruising speed of 15 mph for traffic lanes within indirect sources is made on the basis of observations made within a major shopping center.[20]

6.4 Assumptions Used in Evaluating Background Concentrations

Background concentrations of CO are the result of:

(1) General urban background levels of CO, and

(2) Increases in general urban background levels due to vehicular activity in and around the indirect source but not in the immediate vicinity of the receptor.

The value of "5 ppm" suggested in Section 4.3.3 for adding to the maximum observed 1-hour CO concentration at the site of a proposed source was obtained by comparing observed 1-hour CO values at monitoring sites near the upwind edge of a regional shopping center's parking lot with those near the downwind edge of the lot.[20] The comparisons were confined to periods in which the wind speed was less than 2 m/sec and to stations which were located within the parking lot but not in the vicinity of entrance/exit gates. The value "5 ppm" is representative of the larger differences observed between upwind and downwind sites, and is assumed to represent the impact of emissions within the parking lot. The "2 ppm" value to be added to the observed 8-hour maximum concentration was obtained by multiplying the "5 ppm" 1-hour value by a meteorological persistence factor of 0.6 and by a ratio of peak 8-hour traffic demand to peak 1-hour traffic demand of 0.67. The basis for the "0.6" persistence factor has been described in Section 6.1. The "0.67" value is based on a report prepared for EPA on traffic characteristics in and around regional shopping centers.[40]

7.0 REFERENCES

(1) 40 CFR 52; "Approval and Promulgation of Implementation Plans: Review of Indirect Sources"; Federal Register; (July 9, 1974), p. 25292.

(2) 40 CFR 52; "Approval and Promulgation of Implementation Plans: Proposed Amendments to Parking Management Regulations"; Federal Register; (August 22, 1974); p. 30440.

(3) 40 CFR 51; "Preparation, Adoption, and Submittal of Implementation Plans: Maintenance of National Ambient Air Quality Standards"; Federal Register; (June 18, 1973), p. 15834.

(4) U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards; "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 1: Designation of Air Quality Maintenance Areas" EPA-450/4-74-001, (September 1974); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(5) U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards; "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 2: Plan Preparation"; EPA-450/4-74-002; (July 1974); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(6) U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards; "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 3: Control Strategies"; EPA-450/4-003; (July 1974); Air Pollution Technical Information Center, Research Triangle Park, N.C. 27711.

(7) U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards; "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 4: Land Use and Transportation Considerations"; EPA-450/4-74-004; (August 1974); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(8) U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards; "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 5: Case Studies in Plan Development"; EPA-450/4-74-006; (In preparation); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(9) U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards; "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 6: Overview of Air Quality Maintenance Area Analysis"; EPA-450/4-74-007; (September 1974); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(10) U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards; "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 7: Projecting County Emissions"; EPA-450/4-74-008; (September 1974); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(11) U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards; "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 8: Computer-Assisted Area Source Emissions Gridding Procedure"; EPA-450/4-74-009; (September 1974); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(12) U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards; "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 9: Evaluating Indirect Sources"; EPA-450/4-75-001; (January 1975); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(13) U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards; "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 10: Reviewing New Stationary Sources"; EPA-450/4-74-011; (September 1974); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(14) U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards; "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 11: Air Quality Monitoring and Data Analysis"; EPA-450/4-74-012; (September 1974); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(15) U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards; "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 12: Applying Atmospheric Simulation Models to Air Quality Maintenance Areas"; EPA-450/4-74-013; (September 1974); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(16) U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards, Volume 13: Allocating Projected Emissions to Sub-county Areas"; EPA-450/4-74-014; (In preparation); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(17) "Assessment of Photochemical Oxidant and Nitrogen Dioxide Ambient Concentrations from 3-C Plans"; Volume 1 - Guidance Manual (January 1975); Volume 2 - Technical Backup Document (April 1975); Under preparation for U.S. EPA, OAQPS, Strategies and Air Standards Division, Research Triangle Park, N.C. 27711.

(18) U.S. EPA, Quality Assurance and Environmental Monitoring Laboratory, "Carbon Monoxide Measurements in Vicinity of Shopping Centers"; EPA-450/3-74-048; (April 1973); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(19) Bach, W. D., B. W. Crissman, C. E. Decker, J. W. Minear, P. P. Rasberry and J. B. Tommerdahl; "Carbon Monoxide Measurements in the Vicinity of Sports Stadiums"; EPA-450/3-74-049; (July 1973); U.S. EPA, Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(20) Patterson, R. M., R. M. Bradway, G. A. Gordon, R. G. Orner, R. W. Cass and F.A. Record; "Validation Study of an Approach for Evaluating the Impact of a Shopping Center on Ambient Carbon Monoxide Concentrations"; EPA-450/3-74-059; (August 1974); U.S. EPA, Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(21) Patterson, R. M. and F. A. Record; "Monitoring and Analysis of Carbon Monoxide and Traffic Characteristics at Oakbrook"; EPA-450/3-74-058; (November 1974); U.S. EPA, Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(22) Highway Research Board; "Highway Capacity Manual 1965"; Special Report 87; NAS-NRC; Washington, D.C. (1965).

(23) 40 CFR 50.1 (e); "National Primary and Secondary Air Quality Standards: Definitions"; Federal Register 36; (November 25, 1971); p. 22384.

(24) U.S. DHEW; Public Health Service, National Air Pollution Control Administration; "Air Quality Criteria for Carbon Monoxide"; NAPCA Publication Number AP-62; (March 1970); Washington, D. C.

(25) U.S. EPA Office of Air Programs; "Mixing Heights, Wind Speeds and Potential for Urban Air Pollution Throughout the Contiguous United States"; Office of Air Programs Publication Number AP-101; (January 1972); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(26) U.S. EPA, "Compilation of Air Pollutant Emission Factors"; Publication Number AP-42; Supplement #5 to the Second Edition; (In Press.); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(27) 40 CFR 85; "1975 Federal Test Procedure," Federal Register 36, No. 128; (July 2, 1971).

(28) U.S. EPA, Office of Planning and Evaluation; "Report on the Economic and Land Use Impact of Regulations to Review New Indirect Sources of Air Pollution Prior to Construction"; To be available through the National Technical Information Service, Springfield, Virginia, 22161.

(29) Hillier, F. S. and G. J. Lieberman; Introduction to Operations Research; Holden-Day, Inc.; San Francisco, California (1967), Chapter 10.

(30) Zimmerman, J. R. and R. S. Thompson; "User's Guide for HIWAY: A Highway Air Pollution Model"; Environmental Monitoring Series EPA-650/4-008; National Environmental Research Center, U.S. EPA, Research Triangle Park, N.C. 27711; (In preparation).

(31) McElroy, J.L. and F. Pooler, Jr.; "St. Louis Dispersion Study Volume II--Analysis"; NAPCA Publication Number AP-53; (December 1968); U.S. EPA, Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(32) Clarke, J. F. and K. F. Zeller; "Tracer Study of Dispersion from a Highway"; Paper presented at the Symposium of Atmospheric Diffusion and Air Pollution; American Meteorological Society; (September 9-13, 1974); Santa Barbara, California.

(33) Smith, J. H., W. B. Johnson, F. L. Ludwig, R. E. Inman, L. A. Cavanagh and L. Salas; Air Quality Impact Study for Proposed Highway Widening Near Ojai; Part 1-A; Chapter V, "Microscale Tracer Experiment"; Report prepared for State of California Dept. of Transportation and the Federal Highway Administration, SRI Project 2852, Contract J-7290; (July 1974).

(34) Kunselman, P., H. T. McAdams, C. J. Domke and M. Williams; "Automobile Exhaust Emission Modal Analysis Model"; EPA-460/3-74-005; (January 1974); National Technical Information Service; Springfield, Virginia 22161.

(35) Williams, M. E., J. T. White, L. A. Platte and C. J. Domke; "Automobile Exhaust Emission Surveillance--Analysis of the FY 72 Program"; EPA-460/2-74-001; (February 1974); National Technical Information Service; Springfield, Virginia 22161.

(36) Ashby, H. A., R. C. Stahman, B. H. Eccleston and R. W. Hurn; "Vehicle Emissions--Summer to Winter"; Paper Number 741053 Presented at the SAE Automobile Engineering Meeting, Toronto, Canada; (October 21-25, 1974); Society of Automotive Engineers, Inc.; 400 Commonwealth Drive, Warrendale, Pa. 15096.

(37) Miles, D. L. and M. F. Homfeld; "The Effect of Ambient Temperature on Exhaust Emissions of Cars with Experimental Emission Controls"; Paper Number 741052 Presented at the SAE Automobile Engineering Meeting, Toronto, Canada; (October 21-25, 1974); Society of Automotive Engineers, Inc.; 400 Commonwealth Drive, Warrendale, Pa. 15096.

(38) Grinberg, L. and L. Morgan; "Effect of Temperature on Exhaust Emissions"; Paper Number 740527 Presented at the SAE Combined Commercial Vehicles and Fuels and Lubricants meetings; Chicago, Illinois; (June 17-21, 1974); Society of Automotive Engineers, Inc.; Two Pennsylvania Plaza, New York, New York 10001.

(39) Johnson, B. C.; Barton-Aschman Associates, Inc.; Chicago, Illinois 60626. Personal communication.

(40) Thayer, S. D. and K. Axetell, Jr.; "Vehicle Behavior in and Around Complex Sources and Related Complex Source Characteristics Volume 1--Shopping Centers"; EPA-450/3-74-003-a; National Technical Information Service, Springfield, Virginia 22161.

APPENDIX A. METHODS FOR ESTIMATING EMISSIONS FROM HIGHWAYS

This appendix is intended to provide guidance concerning a more detailed analysis of proposed indirect sources should this be necessary or desirable pursuant to 40 CFR 52.22(b). The materials contained herein are offered as suggestions. Alternate analytical approaches for evaluating the impact of a proposed source may be used if it can be demonstrated that they are more applicable to the source under review.

U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, N. C. 27711

January 1975

APPENDIX A.

METHODS FOR ESTIMATING EMISSIONS FROM HIGHWAYS

The purpose of this Appendix is to assist air pollution control agencies or developers in estimating CO, HC, and NO_x emissions resulting from the use of a new or improved highway. In accordance with Federal regulations on indirect sources,[1] the estimated emissions may then be used as a basis for determining whether construction and operation of one or more sections of the highway is consistent with the applicable SIP requirements (macro-analysis). In addition, the estimated emissions may be used to assess the impact of the highway and its access roads on ambient CO concentrations in the immediate vicinity of the right-of-way (micro-analysis). It should be acknowledged from the outset that there is a wealth of information concerning the operation, design and environmental impact of highways which has been published by the Federal Highway Administration and professional journals in the field of traffic engineering. Some of these references are documented in the section on supplemental references. It should also be pointed out that there are a great many potential environmental impacts other than air quality attendant with the construction or improvement of a highway. These are discussed in some detail in EPA's "Guidelines for Review of Environmental Impact Statements, Volume 1, Highway Projects."[2] The analysis herein has the more limited objectives of relating key highway design and operating variables to emissions. Estimated emissions may then, ultimately, be related to air quality using procedures similar to those outlined in Appendix H.

This appendix presents procedures for estimating emissions for macro- and micro-analyses of a highway's impact on air quality in sections AI and AII. These summaries are then followed by discussions of how the information needed to implement the procedures might best be obtained.

"Macro-analysis" addresses the impact of the source on emissions over areas which are usually thought of as at least 1 km^2. "Micro-analysis" pertains to estimating CO emissions so that the distribution of CO concentrations in the immediate vicinity of the roadway may be estimated. Such an analysis is primarily of interest in determining peak CO concentrations to which people are likely to be exposed.

AI. Procedure for Estimating Emissions from Highways for Macro Analysis

1. Obtain the design and operating parameters indicated in Table A1 from the applicant. Consider each direction separately, and divide the highway into segments as determined by access roads or changes in design.

2. Determine whether Eq. (A4) or (A5) is appropriate to estimate emissions. If Eq. (A5) is acceptable proceed as indicated below. If Eq. (A4) must be used, follow the procedures in Supplement Number 5 to AP-42[3] to estimate emission factors for light and heavy-duty vehicles separately. Correct for cold start percentages differing from 20% and for ambient temperatures, differing from those used in the Federal Test Procedure,[4] using factors presented in Section 4.4 of the screening procedure or techniques presented in Supplement Number 5 to AP-42.[3]

3. Obtain segment lengths (d_1) from plans.

4. Obtain HC and NO_x emission factors (ef) for the appropriate year from Table A3.

5. Obtain traffic volume demand (v_i) for each road segment during the peak 6-9 A.M. use period when smog is likely to be a problem,

using Eq. (A7). Obtain average traffic volume demand for each road segment, using Eq. (A9).

6. If mass transit has not been considered, replace the volume demands obtained in Eqs. (A7) or (A9) with those obtained with Eqs. (A8) or (A9a).

7. If the capacity of each road segment (c_i) is not provided, use Eq. (A10) and Tables A5 and A6 to estimate (c_i). Then use Figures A2, A3, A4 or A5 to estimate the average operating speed in each segment given the average highway speed and v_i/c_i.

8. Use the operating speed to estimate the speed correction factor ($c(s)_i$) obtained using Table 3.1.2-6a in Supplement Number 5 to AP-42.[3]

9. Calculate the total HC and NO_x emissions from the highway using Equations (A5) or (A4).

10. Compare the emissions estimated using steps 1-9 with the emissions which would occur if the highway were not built, in order to estimate the net impact of the highway on total emissions.

AII. Procedure for Estimating Emissions for Micro Analysis of a Roadway

1. Estimate traffic demand for each lane j in road segment i using Eqs. (A12) or (A13). If necessary, adjust the demand for the impact of mass transit using Eqs. (A14) or (A15). Apportion demand among lanes based on local conditions, making sure that Eq. (A2) is satisfied.

2. If the analysis does not concern an at-grade intersection, estimate capacity of the road segment using Eq. (A10) and the lane capacities using Eq. (A16). Check that Eq. (A3) is satisfied. If not, adjust the lane capacities so that Eq. (A3) is satisfied.

3. Determine volume to capacity ratios (v_{ij}/c_{ij}) for each lane.

4. Given the type of road and the average highway speed, use the appropriate one of Figures A2-A5 to estimate operating speeds (S_{ij}) for each lane.

5. Use Figure A6 to estimate the speed-corrected emission factor $(EF)_{ij}$ for each lane. For years other than 1975, adjust this emission factor using Equation (A17). Correct for cold start and ambient temperatures using Section 4.4 in the screening procedure or Supplement Number 5 to AP-42.[3] If local emission factor data are available, multiply the factor thus obtained by an appropriate local correction factor.

6. Use Equation (A11) to estimate the line source emission intensity (q) for each lane of traffic.

7. For at-grade signalized intersections, use information concerning signal cycle lengths and green time to signal cycle ratio to estimate queue lengths with Eq. (A18). Consider emissions over the queue to be the sum of emissions resulting from freely flowing traffic and excess emissions. Elsewhere emissions are attributable to freely flowing traffic. Calculate excess emissions using Eq. (A19). Alternatively, use the information in Tables A8-A12 directly to estimate appropriate emissions and queue length.

8. For non-signalized intersections, estimate average queue length using Eq. (A20). Use Eq. (A21) to estimate the emission intensity over the queue at the intersection approach. Estimate the distance over which vehicles may accelerate and decelerate using Eq. (A22). The emission intensity over this distance is estimated using Eq. (A23). Use Eq. (A11) to estimate emission intensity elsewhere.

AIII. Identification of Key Design and Operating Variables

Any methodology appearing in a set of Federal guidelines must necessarily be general in scope. Therefore, these guidelines should serve the purpose of identifying highway design and operating variables to which emissions are most sensitive. Determination of the values of key design, and operating variables is heavily dependent on local conditions. Therefore, it is necessary that these parameters be assessed on a case-by-case basis by personnel familiar with traffic engineering concepts. Once values for the key variables are estimated, they can be related to emissions using the methodology described herein.

Table A1 presents key variables which ideally should be supplied by the developer or appropriate highway department for the analysis to proceed. Road segments may be conveniently defined as the portions of roads between adjacent exits/entrances. In analyzing the impact of a highway on air quality, it is desirable to divide the highway into segments, because the traffic volume demand and the nature of the traffic (i.e. number of trucks, etc.) are likely to change from segment to segment. Such changes, in addition to imposing varying demands on the capacities needed to avoid congestion (and the resulting higher emissions), may actually affect the capacity itself. For example, if one segment has more truck traffic than another, its capacity will be less, all other factors being equal. Traffic capacity per lane per road segment is a key design parameter, because it provides a means for determining when traffic volume demands will result in congestion thereby causing high emissions. Design speed is primarily of importance in determining speeds (and therefore emission factors) under various volume demand-to-capacity ratios. Vehicle speed and volume demand-to-capacity ratios determine the level of service* occurring on a road. Right-of-way is of

---

*Level of service is the degree of operational freedom available on the highway.

Table A1. KEY HIGHWAY DESIGN AND OPERATING VARIABLES FOR ESTIMATING VEHICULAR EMISSIONS

Variable	Remarks
Traffic Capacity per Lane per Road Segment (including merge lanes).	A road segment is ordinarily that portion of a highway between adjacent entrance/exits. Capacity is consistent with Level of Service
Design Speed	This variable would ordinarily be the posted speed limit.
Right-of-Way and Median width	
Number of Lanes per Road Segment	
Access Road Capacity per Lane	Consistent with Level of Service E
Number of Lanes per Access Road (For key access roads) and number of merge lanes	A key access road would ordinarily be one in which traffic volume demand approaches access road capacity.
Annual Average Daily Traffic (AADT) for each segment	Even more desirable would be the AADT per lane per segment if the demand is expected to be substantially different for different lanes in a segment.
Seasonal, Weekly and Diurnal Use Patterns	
Estimated Peak 1-hour, 8-hour Traffic Volume Demand per Road Segment	
Vehicle Mixes Utilizing Segments	For example, age mixes and proportions of light, medium and heavy-duty vehicles.

Table A1 (continued)

Variable	Remarks
Plans or Blueprints of the Highway, its Route and Access Roads	Needed to identify road segments for each direction.
Average Highway Speed	Weighted average of design speeds within a highway segment
Green time to Signal Cycle Ratio	Used in estimating capacity at intersections
Cycle Length	The sum of time a traffic signal spends in each phase of the signal cycle. Useful in estimating queue lengths upstream from intersections
Location of the road segment evaluated	Central business district, fringe areas, outlying business district, residential, rural areas

interest in selecting sensitive receptor sites. Ordinarily, such a site would not occur within the right-of-way. Number of lanes per road segment is important to know in applying a line source diffusion model to estimate CO concentrations in the vicinity of the highway. In addition, number of lanes per segment is one of several determinants of the segment's capacity and would be needed to estimate capacity if estimates of this parameter were not directly available. Number of lanes and capacities for access roads are important, because the peak impact of a major highway may occur at sensitive receptors in the vicinity of on- or off-ramps. The three operational parameters (AADT, use rate patterns and peak demands) are important for two reasons:

1. As an estimate of the sheer numbers of vehicles using road segments.
2. As an indicator (along with capacity) of whether congestion is likely.

The vehicle mix utilizing each segment is a determinant of the appropriate emission factor per segment as well as the segment's capacity.

AIV. Scope of Analysis and Basic Concepts

Table A2 summarizes the types of analyses required for highway projects of various sizes.

Table A2. TYPES OF ANALYSES REQUIRED FOR HIGHWAY PROJECTS

	Macro and Micro Analysis Required	Only Micro Analysis in SMSA's Required
Construction of a new Highway	Anticipated AADT* $\geq$ 50,000	Anticipated AADT $\geq$ 20,000
Modification of an existing Highway	Anticipated Increase in AADT $\geq$ 25,000	Anticipated Increase in AADT $\geq$ 10,000

*Annual Average Daily Traffic, vehicles/day

Figure A1 is a schematic drawing of one segment of one direction of an 8-lane highway. In Figure A1, the v's represent volume demand (vph). The first numerical subscript refers to the road segment, while the second numerical subscript refers to the lane within the segment. The first lane is defined as the outside lane. The letter subscripts are interpreted as follows: "x" stands for exiting traffic; "e" stands for entering traffic, and "t" stands for through traffic. The "d's" in Figure A1 represent the length of a given road segment. For any road segment, the traffic volume demand is given by Eq. (A1).

$$v_{i,t} = v_{i-1,t} + v_{i,e} - v_{i,x} \qquad \text{(A1)}$$

Thus for road segment 1 in Figure A1,

$$v_{1t} = v_{ot} + v_{1e} - v_{1x} \qquad \text{(A1a)}$$

Also, for any road segment, the traffic volume demand is the sum of the demands in all the lanes.

$$v_{it} = \sum_{j=1}^{m} v_{ijt} \qquad \text{(A2)}$$

or, as applied to Figure A1,

$$v_{1t} = v_{11t} + v_{12t} + v_{13t} + {}_{14t} \qquad \text{(A2a)}$$

The traffic volume demand can be determined for a segment if a direct estimate is provided by the developer or if estimates for all preceding exit and entrance demands are known and an estimate of the traffic volume demand entering the area of interest (i.e. v_{ot}) is provided. It would be most convenient if the traffic volume demands were

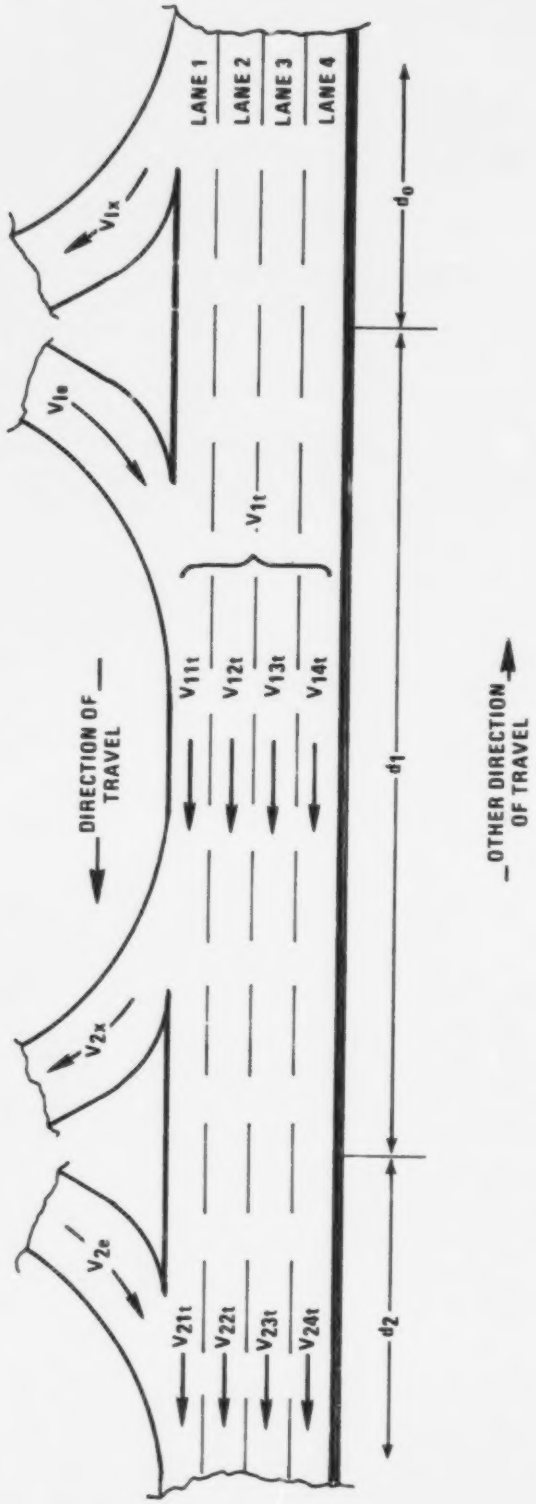

LANE 1
LANE 2
LANE 3
LANE 4
V_{1x}
V_{1e}
V_{1t}
V_{11t}
V_{12t}
V_{13t}
V_{14t}
DIRECTION OF TRAVEL
V_{2x}
V_{2e}
V_{21t}
V_{22t}
V_{23t}
V_{24t}
d_0
d_1
d_2
OTHER DIRECTION OF TRAVEL

Figure A1. Schematic diagram for analysis of a major highway.

approximately the same for each lane. Unfortunately, this frequently may not be the case. For example in Figure A1, if lane 4 were designated as a mass transit (bus) lane and lane 1 were used primarily by exit and entrance traffic, there might be an appreciable difference in traffic volume demand among lanes. Given the information which is usually available however, it may only be possible to identify traffic flow by direction. Information about the amount of traffic entering and exiting (or turning on arterial roads) may be used as a basis for more refined apportionments in each direction if such information is available. Making reference once again to Figure A1, with similar notation, the following definitions and relationships apply with respect to capacity. "c_{it}" is the capacity of lane j in segment i.

$$c_{it} = \sum_{j=1}^{m} c_{ijt} \tag{A3}$$

or for Figure A1,

$$c_{1t} = c_{11t} + c_{12t} + c_{13t} + c_{14t} \tag{A3a}$$

Capacity is determined by a number of factors, many of which can only be determined upon examination of plans including information about such considerations as volume demands and capacities on succeeding road segments, demands and capacities on access roads, and presence of turning or exit/entrance lanes. In addition to determinants of capacity which can only be determined upon study of detailed plans, there are several determinants whose effects can be gauged on a more general basis. These include such operating and design parameters as lane width, lateral clearance, percentage of trucks utilizing the highway, design speed and grade.

AV. Estimating Emissions for Macro Analysis

With the basic concepts, definitions and relationships presented in Figure A1 and Equations (A1) - (A3) in mind, the procedure described below may be used to derive emissions from the proposed new or improved highway. Emissions may be estimated using Equation (A4).

$$Q = \sum_{i=o}^{n} (d_i)(ef)_{ldv}(c(s))_{il}(v_i)_{ldv} + \sum_{i=o}^{n} (d_i)(ef)_{HDV}(c(s))_{ih}(N_i) \quad (A4)$$

where

$(ef)_{ldv}$ = emission factor from light-duty vehicles (including 88% automobiles and 12% light-duty trucks), operating at an average speed of 19.6 mph during the calendar year of interest, gm/mi-veh.

$c(s)_{il}$ = speed correction factor to emission factors applicable to road segment i for light-duty vehicles (use information compiled in Tables 3.1.2-6a and 3.1.2-6b in Supplement Number 5 to AP-42[3]). Assume the relationships for model year 1972 hold for later models as well.

v_i = volume demand for light-duty vehicles, vph.

d_i = length of segment i, mi.

$(ef)_{HDV}$ = emission factor from heavy-duty vehicles (trucks, buses) gm/veh-mi.

$c(s)_{ih}$ = speed correction factor for heavy-duty vehicles. Unless information is available to the contrary, use the same speed correction factors as for light-duty vehicles.

N_i = volume demand for heavy-duty vehicles, vph.

n = number of road segments in the area of interest.

Q = emission rate from all road segments, gm/hr.

If the projected vehicle mix for the highway appears to be dominated by light-duty vehicles, Eq. (A4) can be simplified as expressed in Equation (A5).

$$Q = \sum_{i=o}^{n} (d_i)(ef)(c(s))_i \, (v_i) \qquad \text{(A5)}$$

where

ef = average emission factor for the calendar year of interest, gm/mi-veh.

$c(s)_1$ = speed correction factor.

v_i = volume demand (all vehicles on road segment i), vph.

If the mix of model years is typical, Tables A3 may be used to estimate emission factors (ef) for various calendar years. If the projected traffic mix for a highway indicates that this simplified procedure is not appropriate, Supplement Number 5 to AP-42 should be consulted.[3] The resulting emission factors would then be used in Equation (A4). For illustrative purposes, the subsequent analysis assumes that the simplifying assumptions are reasonable and that Equation (A5) may be used.

Eq. (A5) could be simplified still further provided the operating conditions and mix of traffic which would utilize the new or modified highway are not significantly different from that using the existing configuration of roads. Instead, "equivalent vehicle miles traveled (EVMT)" may be estimated using Eq. (A6) and compared with the EVMT which is estimated for the case in which the highway is not built.

$$EVMT = \sum_{i=o}^{n} (d_i)\,(c(s)_i)(v_i) \qquad \text{(A6)}$$

TABLE A3. COMPOSITE EMISSION FACTORS BY CALENDAR YEAR ASSUMING 88 PERCENT LDV TRAVEL AND 12 PERCENT LDT TRAVEL (NO HDV)*

Low Altitude, Non-California
Pollutant, gm/mi

Calendar-Year	CO	HC[1]	HC[2]	NO_x
1975	55.0	5.3	2.3	4.0
1976	48.2	4.8	2.3	4.0
1977	42.0	4.3	2.2	3.8
1978	35.8	3.8	2.1	3.4
1979	29.9	3.2	2.1	3.0
1980	24.1	2.8	1.8	2.6

High Altitude, Non-California
Pollutant, gm/mi

Calendar-Year	CO	HC[1]	HC[2]	NO_x
1975	97.2	7.1	3.0	3.0
1976	86.4	6.5	2.8	3.2
1977	77.3	5.8	2.7	3.2
1978	66.9	5.2	2.6	3.0
1979	56.0	4.5	2.4	2.7
1980	45.6	3.8	2.3	2.4

California
Pollutant, gm/mi

Calendar-Year	CO	HC[1]	HC[2]	NO_x
1975	53.9	5.2	2.2	3.8
1976	44.9	4.7	2.1	3.6
1977	41.4	4.2	2.1	3.4
1978	33.8	3.6	2.1	3.1
1979	28.5	3.1	2.1	2.6
1980	23.3	2.7	1.8	2.4

*Reflects interim emission standards through the 1977 model year and statutory standards thereafter. If amendments to the Clean Air Act proposed in March 1975 become law, Appendix D in Supplement 5 to AP-42 should be used to derive new factors for 1978 and later years.

[1] Excludes evaporative and crankcase hydrocarbons. Speed correction factors apply.

[2] Evaporative and crankcase hydrocarbons. Speed correction factors do not apply.

A. Length of Road Segments (d_i)

This parameter would be determined directly from the plans provided by the developer. Each direction would be considered separately in dividing the road into segments.

B. Emission Factors (ef)

Emission factors for the appropriate year should be obtained from Table A3 or from AP-42.[3] These factors are appropriate for "average" trip speeds, and reflect the combination of acceleration, deceleration and constant-speed traveling used in the 1975 Federal Test Procedure.[4] If information were available about the likely proportions of time to be spent in different operational modes (e.g. acceleration, deceleration, constant speed), a more satisfactory procedure would be to combine emission factors for each mode in accordance with each mode's relative importance to obtain average trip emission factors.

C. Traffic Volume Demand (v_i)

The traffic volume demand estimate which should be used in Eqs. (A5) or (A4) depends upon the applicable standard for the pollutant of concern. In any case however, projected traffic volume demand should reflect diverted and induced traffic as well as possible. Diverted traffic is the result of trips which are diverted from other road(s) to the new or modified highway. For example, the presence of the highway might make it much more convenient to utilize shopping center A rather than shopping center B which is located in a different area. The result is an increase in traffic along the route caused by people formerly using different routes to arrive at shopping center B. Induced traffic is caused by attractions building up along the route of the highway and generating trips. The amounts of diverted and induced traffic depends entirely on local conditions, so that only qualitative suggestions for their determination can be provided here. The economic-demographic determinants of traffic demand enumerated in Section 5.0 in "Guidelines for the Review of the Impact of Indirect Sources on Ambient Air Quality" should be checked for relevance. Land use and other maps plotting census information may provide additional insight in estimating diverted and induced demand.

1. HC

Total non-methane hydrocarbons are primarily of interest, because they appear to be precursors of oxidants. Therefore, in estimating hydrocarbon emissions from highways, one is indirectly assessing the effect of a highway's presence on oxidant concentrations. The standard for hydrocarbons is for 3 hours which must be met between the hours of 6 A.M. - 9 A.M. in areas where there is difficulty in meeting the oxidant standard. Hence, one period in which the traffic volume demand may be of interest is the peak one occurring during 6-9 A.M. at times of the year in which photochemical oxidant formation has been observed as a problem. The traffic demand during such periods may be determined as follows for use in Equation (A5).

(a) Start with the estimated annual average daily traffic (AADT), veh/day.

(b) Multiply AADT by the peak seasonal adjustment factor during which oxidants are a problem to get peak seasonal average daily traffic. Peak seasonal adjustment factors depend on the area of the country in which the road is located and whether the highway is urban or rural. Estimates of seasonal variations in traffic should also be required from the applicant.

(c) Multiply peak seasonal average daily traffic by a factor denoting the use of the highway during 6-9 A.M. on the busiest day of the week. If this information is not available from the developer, it has been estimated [5,6] that for urban highways, the Friday morning 6-9 A.M. period is likely to be busiest. The fraction which traffic utilizing the highway during this period constitutes of the average daily traffic during the season of peak daily use has been estimated as shown in Table A4.[7]

Table A4. PEAK USE FACTORS

Type of Road	Peak 6-9 A.M. Use Daily Traffic in Peak Season
Urban freeways	.22
Suburban freeways	.20
Urban arterials	.20
Rural arterials	.17

Summarizing steps (a) - (c), the traffic volume demand during 6 - 9 A.M. may be estimated using Eq. (A7).

$$v_i = \frac{(\text{AADT})_i \begin{pmatrix}\text{Seasonal Adjustment} \\ \text{Demand Factor}\end{pmatrix} \left[\frac{(\text{6-9 A.M. traffic})}{(\text{daily traffic during peak season})}\right]}{3} \tag{A7}$$

where

$(\text{AADT})_i$ = annual average daily traffic estimated for road segment i, veh/day

1/3 = conversion factor from (3-hr) to (1-hr)

v_i = vph

If mass transit use is not already implicitly accounted for in the estimates of v_i should be adjusted as shown in Eq. (A8).

$$v_i = \text{Eq. (A7)} - \frac{(T)(P)}{(3)(\text{avo})} + \frac{B_i}{3} \tag{A8}$$

where

T = the number of mass transit passengers during the peak 6-9 A.M. period

P = the fraction of passengers who would normally use a private auto were the mass transit facilities not available

(avo) = the average number of passengers per auto

B_i = the number of mass transit buses using road segment i during the peak 6-9 A.M. period.

2. $\underline{NO_2}$

Since the standard for NO_2 is an annual one, AADT may be used directly to estimate mean traffic volume demand for road segments.

$$v_i = \frac{(AADT)_i}{24} \tag{A9}$$

where 1/24 = conversion factor from veh/day to vph

Similarly, if mass transit is not accounted for in the estimate of v_i, use Eq. (A9a) to obtain an adjusted traffic volume demand.

$$v_i = \text{Eq. (A9)} - \frac{(T)(P)}{(24)(avo)} + \frac{B_i}{24} \tag{A9a}$$

where

T = average number of mass transit passengers during a day

P = fraction of passengers normally using a private auto

B_i = average daily number of mass transit buses using road segment i, veh/day

(avo) = average number of passengers per auto

Equations (A9) and (A9a) may also be used to estimate average annual daily HC emissions if this is to be used as a criterion for whether or not a proposed highway or highway system is acceptable.

D. Speed Correction Factors $(c(s)_1)$

The speed correction factor used in Eq. (A5) is determined by the average operating speed on road segment i. This speed, in turn, is a function of the highway design speed and the ratio between the volume demand and the capacity for segment i (v_i/c_i ratio). Thus, to determine the appropriate speed correction factor and speed, it is first necessary to estimate the capacity of road segment i (c_i). As indicated earlier, under some circumstances capacity can be largely determined by the design of succeeding road segments or exit/entrance ramps. If these designs are inadequate, they may have a predominant effect on the capacities of preceding segments. However, since the general traffic engineering practice appears to be to design a highway to accommodate the traffic demand at the 30th highest hour maintaining a level of service of "D" or better at the segment with the lowest capacity, the possibility of backups from successive segments occurring during the peak 6-9 A.M. period or during the average day can be ignored. If the information is not available directly from the developer, capacity of segment i can be estimated using Tables A5 and A6 and Equation (A10).

$$c_i = 2000\ M_i\ W_i\ T_i \qquad \text{(A10)}$$

where

M_i = number of lanes (one direction)[*] segment i

W_i = adjustment for lane width and lateral clearance, obtained from Table A5

T_i = truck-bus adjustment factor (which includes an adjustment for grade) obtained from Table A6.

If capacity is likely to alter appreciably from lane to lane, a separate analysis would have to be done for each lane. Once capacity for segment i is known, v_i/c_i ratio can be determined.

The relationship between volume-capacity ratio and operating speed for freely flowing traffic depends on the type of roadway being considered and the average highway speed or posted speed limit. Figures A2-A5 depict these relationships for expressways, multi-lane rural highways, two-lane rural highways, and urban and suburban arterial streets.[8] Relationships shown in Figures A2-A5 are empirical ones based on observations over several years in a number of locations. However, if a specific relationship between volume-capacity ratio and operating speed has been developed

---

[*] A separate analysis should be conducted for each direction.

TABLE A5. COMBINED EFFECT OF LANE WIDTH AND RESTRICTED LATERAL CLEARANCE ON CAPACITY AND SERVICE VOLUMES OF DIVIDED FREEWAYS AND EXPRESSWAYS WITH UNINTERRUPTED FLOW

DISTANCE FROM TRAFFIC LANE EDGE TO OBSTRUCTION (FT)	ADJUSTMENT FACTOR,ᵃ W, FOR LANE WIDTH AND LATERAL CLEARANCE							
	OBSTRUCTION ON ONE SIDE OF ONE-DIRECTION ROADWAY				OBSTRUCTIONS ON BOTH SIDES OF ONE-DIRECTION ROADWAY			
	12-FT LANES	11-FT LANES	10-FT LANES	9-FT LANES	12-FT LANES	11-FT LANES	10-FT LANES	9-FT LANES
(a) 4-Lane Divided Freeway, One Direction of Travel								
6	1.00	0.97	0.91	0.81	1.00	0.97	0.91	0.81
4	0.99	0.96	0.90	0.80	0.98	0.95	0.89	0.79
2	0.97	0.94	0.88	0.79	0.94	0.91	0.86	0.76
0	0.90	0.87	0.82	0.73	0.81	0.79	0.74	0.66
(b) 6- and 8-Lane Divided Freeway, One Direction of Travel								
6	1.00	0.96	0.89	0.78	1.00	0.96	0.89	0.78
4	0.99	0.95	0.88	0.77	0.98	0.94	0.87	0.77
2	0.97	0.93	0.87	0.76	0.96	0.92	0.85	0.75
0	0.94	0.91	0.85	0.74	0.91	0.87	0.81	0.70

ᵃ Same adjustments for capacity and all levels of service.

TABLE A6. AVERAGE GENERALIZED ADJUSTMENT FACTORS FOR TRUCKS ON FREEWAYS AND EXPRESSWAYS, OVER EXTENDED SECTION LENGTHS

PERCENTAGE OF TRUCKS, P_T	FACTOR, T, FOR ALL LEVELS OF SERVICE		
	LEVEL TERRAIN	ROLLING TERRAIN	MOUNTAINOUS TERRAIN
1	0.99	0.97	0.93
2	0.98	0.94	0.88
3	0.97	0.92	0.83
4	0.96	0.89	0.78
5	0.95	0.87	0.74
6	0.94	0.85	0.70
7	0.93	0.83	0.67
8	0.93	0.81	0.64
9	0.92	0.79	0.61
10	0.91	0.77	0.59
12	0.89	0.74	0.54
14	0.88	0.70	0.51
16	0.86	0.68	0.47
18	0.85	0.65	0.44
20	0.83	0.63	0.42

Note: Tables A5 and A6 are taken from Tables 9-2 and 9-3b of Reference 5.

for a road under review, it should be used instead. Use of Figures A2 - A5 to obtain vehicle operating speed is illustrated by this short example. A 6-lane urban freeway with a design speed of 60 mph is proposed. The volume to capacity ratio for segment i is 0.6. What is the operating speed? Since an urban expressway is of interest, Figure A2 is used to obtain an average operating speed of about 45 mph. Therefore, the speed correction factor for the pollutant of interest which corresponds to a speed of 45 mph would be derived from Table 3.1.2-6a in Supplement Number 5 to AP-42.[3]

For HC's; $c(s)_i = 0.59$ (Note that this factor applies to exhaust emissions of hydrocarbons only.)

For NO_x; $c(s)_i = 1.20$

The upper curves should always be used in Figs. A2 - A5 to estimate operating speed unless $v_i/c_i \geq 1$. In this case service level F (forced flow stop and start traffic) should be assumed and speed cannot be determined. Occurrence of level F in the macro analysis would mean a traffic jam lasting at least 3 hours is likely to occur. This should be grounds for redesign of the highway.

AVI. Estimating Emissions for Micro Analysis

Micro analysis of roadways is needed to determine the impact of traffic on nearby 1-hour and 8-hour ambient concentrations of CO. For such a purpose, two considerations are necessary. First the levels of concentration at sensitive receptors attributable to freely flowing traffic on the most heavily used road segment of an expressway or at mid-block locations on major streets may be of interest. Second, concentrations occurring in the vicinity of signalized or unsignalized at-grade intersections may be critical.

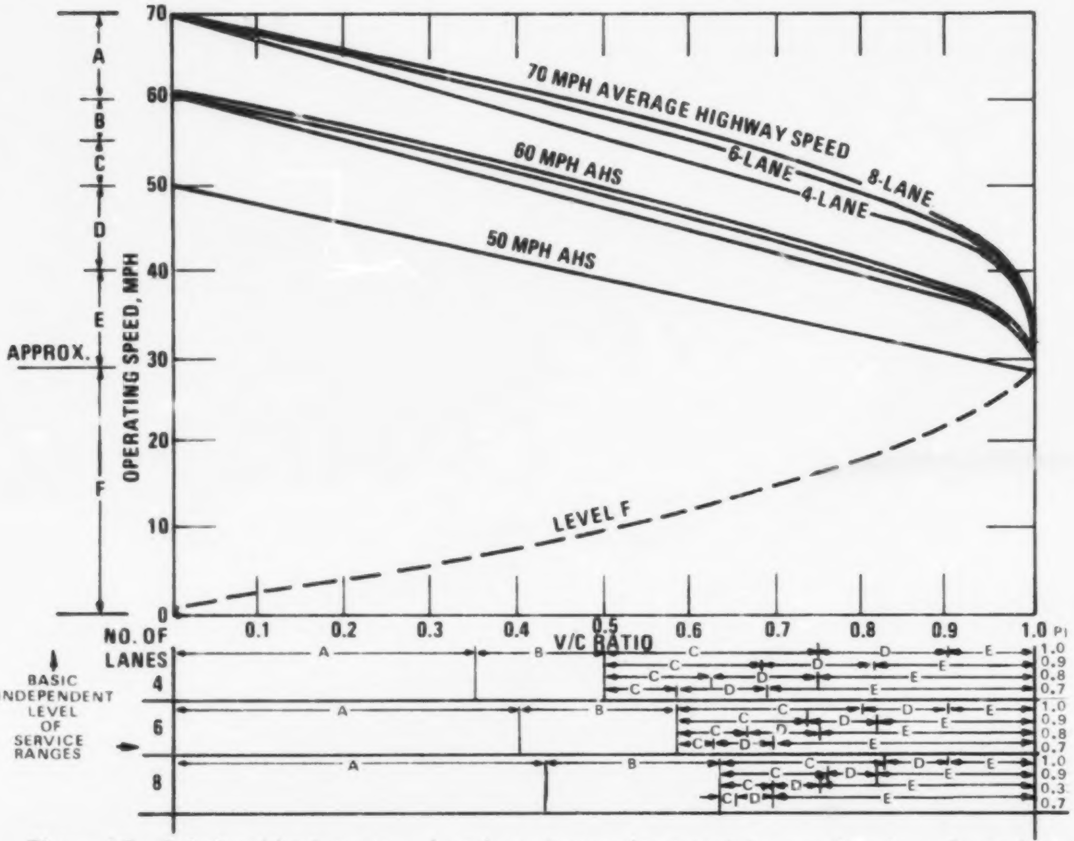


Figure A2. Relationships between v/c ratio and operating speed, in one direction of travel, on freeways and expressways, under uninterrupted flow conditions.

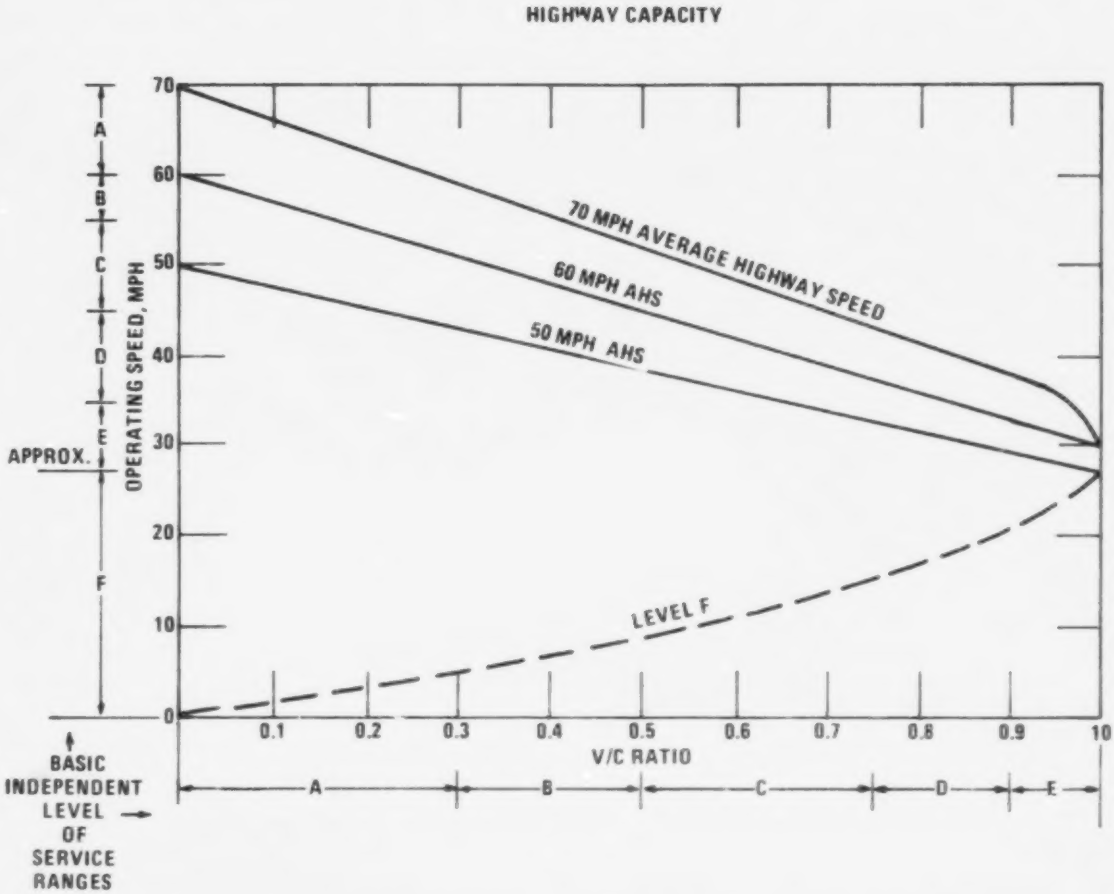


Figure A3. Relationships between v/c ratio and operating speed, in one direction of travel, on multilane rural highways, under uninterrupted flow conditions.

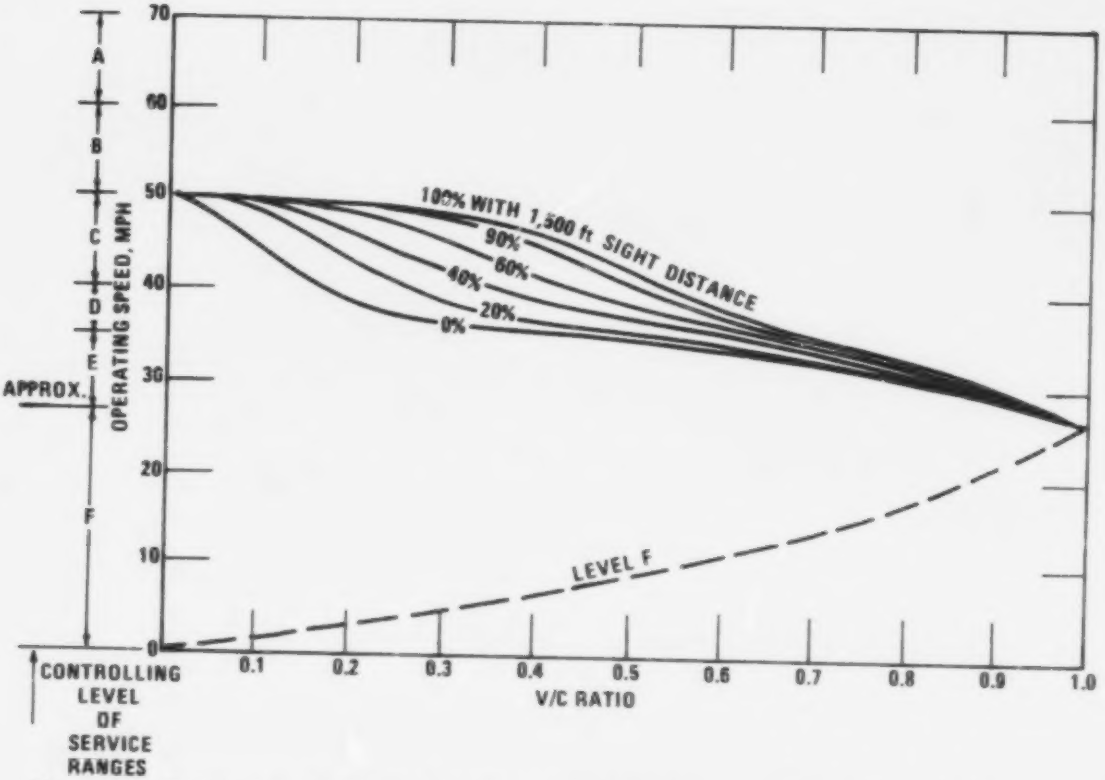
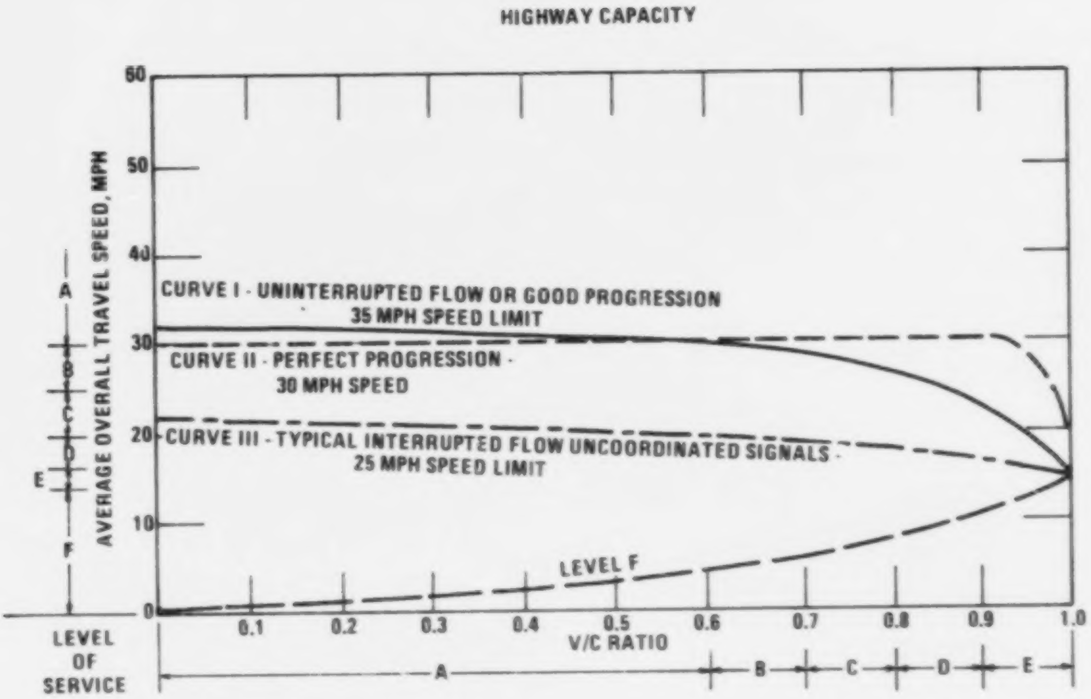


Figure A4. Relationships between v/c ratio and operating speed, overall for both directions of travel, on two-lane rural highways with average highway speed of 50 mph, under uninterrupted flow conditions.



HIGHWAY CAPACITY

Figure A5. Typical relationships between v/c ratio and average overall travel speed, in one direction of travel, on urban and suburban arterial streets.

A. Concentrations Attributable to Freely Flowing Traffic

A line source dispersion model may be used to estimate concentrations in the vicinity of a roadway accommodating such traffic. Since line source models are capable of distinguishing conditions among traffic lanes and variations among lanes may alter predictions, it would be preferable to do a lane-by-lane analysis for emissions. In doing so, the relationships expressed in Equations (A2) and (A3) should be recalled.

$$v_{it} = \sum_{j=1}^{m} v_{ijt} \qquad \text{(A2)}$$

$$c_{it} = \sum_{j=1}^{m} c_{ijt} \qquad \text{(A3)}$$

The basic equation for obtaining line source emission rates by lane is:

$$q_{ij} = (1.036 \times 10^{-5})\,(EF)_{ij}\,(v_{ij}/S_{ij}) \qquad \text{(A11)}$$

where

q_{ij} = line source emission rate in lane j for road segment i, gm/sec-m

$(EF)_{ij}$ = speed corrected emission factor, gm/min-veh for vehicles in lane j of segment i

v_{ij} = traffic volume demand in lane j, segment i, vph

S_{ij} = vehicle operating speed in lane j segment i, mi/hr.

(1.036×10^{-5}) = conversion factor from $\frac{\text{gm}}{\text{min-mi}}$ to $\frac{\text{gm}}{\text{sec-m}}$

1. Traffic Volume Demand Per Lane (v_{ij})

The total traffic volume demand of road segment i can be estimated for 1 and 8-hour periods by beginning with $(AADT)_i$ and multiplying by peak seasonal adjustment factors. Since CO is the pollutant of concern, whether or not photochemical reactions are prevalent need no longer be a factor in choosing the maximum seasonal adjustment factor. The peak seasonal average daily traffic rate would then be multiplied by the peak weekly 1-hour (8 hour) adjustment factor. Thus,

$$v_i = (AADT)_i \begin{pmatrix}\text{Seasonal Adjustment}\\ \text{Demand Factor}\end{pmatrix}\begin{pmatrix}\text{Fraction Peak 1-hr Demand is}\\ \text{of Peak Seasonal Daily Demand}\end{pmatrix} \quad \text{(A12)}$$

or

$$v_i = \frac{(AADT)_i \begin{pmatrix}\text{Seasonal Adjustment}\\ \text{Demand Factor}\end{pmatrix}\begin{pmatrix}\text{Fraction Peak 8-hr Demand is}\\ \text{of Peak Seasonal Daily Demand}\end{pmatrix}}{8} \quad \text{(A13)}$$

where v_i = traffic volume demand for road segment i, vph.

If the information concerning diurnal and weekly variations in traffic patterns is insufficient to use Eqs. (A12) or (A13), information contained in a report prepared for EPA[5] may be used to derive Eqs. (A12a) and (A13a).

$$v_i = (.094) \begin{pmatrix}\text{Seasonal Adjustment}\\ \text{Demand Factor}\end{pmatrix} (AADT)_i \quad \text{(A12a)}$$

$$v_i = \frac{(.50) \begin{pmatrix}\text{Seasonal Adjustment}\\ \text{Demand Factor}\end{pmatrix} (AADT)_i}{8} \quad \text{(A13a)}$$

If seasonal changes are not known, it is suggested that the factors presented in Table A7 be used in Equations (A12a) or (A13a).

Table A7. SEASONAL ADJUSTMENT DEMAND FACTOR

Location AADT	Urban		Rural	
	1-hr.	8-hr.	1-hr.	8-hr.
< 20,000	1.70	1.40	1.70	1.68
20,000 - 50,000	1.38	1.30	*	1.68
> 50,000	1.06	1.20	*	1.40

*Assume each lane accommodates 2000 vehicles per hour and v_i = (number of lanes) (2000).

If the v_i calculated with Equations (A12) and (A13) did not take account of mass transit, the volume demand would have to be adjusted using Equations (A14) and (A15).

$$v_i = \text{Eq. (A12)} - \frac{(T)\ (P)}{(avo)} + B_i \qquad \text{(A14)}$$

$$v_i = \text{Eq. (A13)} - \frac{(T)\ (P)}{8\ (avo)} + \frac{B_i}{8} \qquad \text{(A15)}$$

where P = fraction of passengers normally using a private auto where mass transit is not available

(avo) = average number of passengers per auto

B_i = number of mass transit buses using road segment i during the selected 1- or 8-hour period

T = number of passengers utilizing buses during the selected 1- or 8-hour period

v_i would then be apportioned among the lanes in segment i in accordance with such locally determined considerations as presence of bus lanes and volume demand at nearby exits and entrances. Care should be taken that Eq. (A2) is satisfied in apportioning traffic demand for segment i lanes.

2. Operating Speed Per Lane (S_{ij})

Operating speed may be estimated by v_{ij}/c_{ij} ratio and the average highway speed. It can usually be assumed that the average highway speed is the same for all lanes. The c_{ij} for each lane could be estimated using Eq. (A16).

$$c_{ij} = 2{,}000\ W_{ij}\ T_{ij} \tag{A16}$$

The values of c_{ij} calculated with Eq. (A16) should be checked with Eq. (A3) to make sure c_i is not exceeded. If the capacity of the segment is less than the sum of the lane capacities, the capacity of the lane adjacent to a lateral obstruction should be reduced. Once v_{ij}/c_{ij} is known for each lane, S_{ij} may be estimated using the appropriate one of Figures A2 - A5.

3. Speed Adjusted Emission Factor $(EF)_{ij}$

Figure A6 plots CO emission factors as a function of operating speed for a vehicle mix of light-duty vehicles (composed of 88% cars and 12% light trucks) during 1975. Once the operating speed has been determined, $(EF)_{ij}$ may be obtained from Figure A6. If some year other than 1975 is of interest, the appropriate CO emission factor may be estimated using Eq. (A17).

$$(EF)_{yr} = (EF)_{75} \left[\frac{(ef)}{55} \right] \tag{A17}$$

where

$(EF)_{yr}$ is the emission factor for the year of interest;

$(EF)_{75}$ is the 1975 emission factor obtained from Figure A6;

(ef) is the value of the CO emission factor found in Tables A3 for the year of interest.

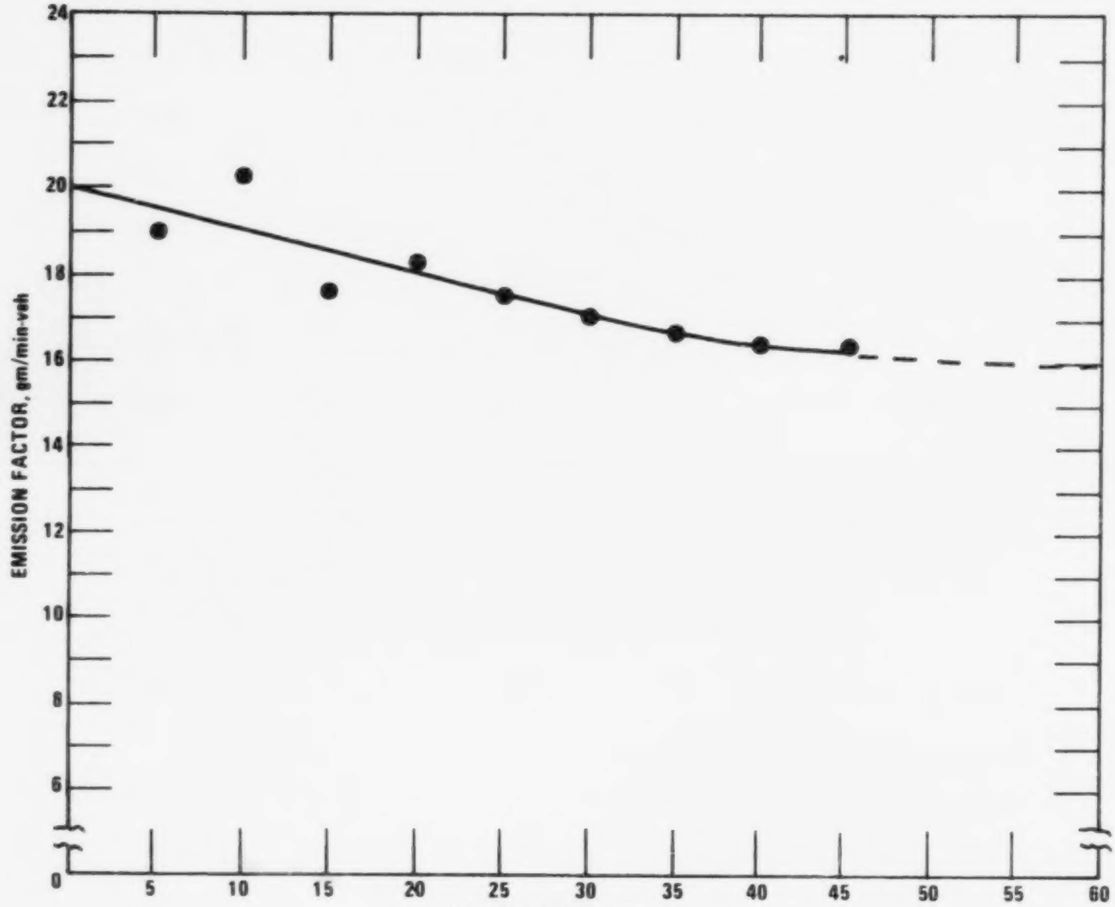


Figure A6. Composite emission factors for carbon monoxide for calendar year 1975.

"55" is the CO emission factor for an average trip with a 1975 mix of vehicles. It should be noted that the emission factor in Figure A6 corresponding to 0 mph is indicative of stop-and-start traffic rather than idling. The emission factors obtained using Figure A6 and Eq. (A17) are appropriate for a national average mix of light-duty vehicles in which 20 percent of the vehicles are operating from cold starts and driving cycles are similar to that used in the 1975 Federal Test Procedure.[4] Ambient temperatures are assumed to range from 68-86°F. Such assumptions may not be appropriate for an individual location. If a national average mix of model years is inappropriate, local emission factors, reflecting a more appropriate mix can be derived by following procedures outlined in Supplement 5 of AP-42.[3] If the assumption of 20 percent cold starts or of ambient temperatures of 68-86°F is inappropriate, derived emission factors can be corrected using Equation (3.1.2-2) and Tables 3.1.2-7 or 3.1.2-8 in Supplement 5 to AP-42.[3] This procedure was followed in deriving the correction factors for CO emission in Section 4.4.1 of the Indirect Source Guidelines. If the driving cycle (i.e., the mix of vehicle operating modes) at a location is not well represented by that used in the 1975 Federal Test Procedure,[4] the EPA Automobile Exhaust Emission Modal Analysis Model,[10] may be used to estimate emissions resulting from any sequence of operating modes. This procedure was followed for signalized intersections in deriving the curves for signalized intersections in Section 4.1.

B. Concentrations in the Vicinity of At-Grade Intersection

Equations (A12) and (A13) may be of use in estimating traffic volume demand at intersections. However, estimating resulting emissions at an approach or at approaches to intersections is more complicated than it is for freely flowing traffic. Two major types of intersection approaches are of interest: signalized and non-signalized. A signalized intersection is distinctive in that queuing may occur at discrete time intervals (i.e., during the red phase of the signal) and traffic may be freely flowing much of the rest of the time. A non-signalized intersection approach (e.g., one having a STOP sign), however, is likely to experience queuing at irregular intervals.

One approach which has been suggested[11] for estimating emissions at signalized intersections is to consider emissions at each intersection approach to be the sum of two components. The first component consists of emissions which would occur if there were no impedence to traffic flow caused by the light. These emissions are estimated using Equation (A11). The second component is that attributable "excess emissions" occurring at each approach to an intersection over a finite distance defined by the average queue length accumulating during the red phase of the signal. Excess emissions occur for three reasons:

(1) As a result of higher emission factors attributable to accelerating vehicles;

(2) As a result of vehicles staying in the approach longer (i.e., when idling during the red phase) than is the case under free-flow conditions; and

(3) As a result of closer spacing between idling vehicles than would occur with freely flowing traffic.

The first step in estimating "excess emissions" is to estimate the average queue length accumulating during the red phase of the signal. Equation (A18) provides a means for doing this.

$$L_{ij} = \frac{v_{ij}\left[1-(G/C_y)_i\right]D}{CPH} \qquad \text{(A18)}$$

where

L_{ij} = average queue length of vehicles accumulating at approach i, lane j during the red phase of a traffic signal, m

v_{ij} = traffic volume demand at intersection approach i, lane j, vph

$(G/C_y)_i$ = green time to signal cycle ratio at approach i, dimensionless

D = spacing (tailpipe-to-tailpipe) between consecutive queuing vehicles, m

CPH = number of signal cycles per hour, hr^{-1}.

Calculation of queue length using Equation (A18) is straightforward at an intersection where the traffic signal is a fixed-time one. However, the use of Equation (A18) is more complicated for a traffic actuated signal. This is because the G/C_y ratio and signal cycle length vary depending upon the traffic demand and the distribution of demand among the approaches to the intersection. Detailed discussions on how to estimate G/C_y ratios for the approaches to intersections having traffic actuated signals are available in several references.[8, 12, 13] The following discussion briefly outlines the procedure which can be used for relatively simple signalized intersections. The discussion is followed by a short numerical example.

(1) Estimate the capacity (consistent with Level of Service E) for each intersection approach as if the intersection did not exist. This can be done using Equation (A10) and Tables A5 and A6 as appropriate.

(2) Estimate volume demand-capacity ratios (v/c)' for each approach, using the capacities estimated in Step (1).

(3) Note the intersection leg having the highest (v/c)' ratio for each phase of the traffic signal.

(4) Add the highest (v/c)''s for each phase of the signal. Add "0.1" to the total to account for the time that the signal is amber. The sum is the (v/c)' for the intersection.

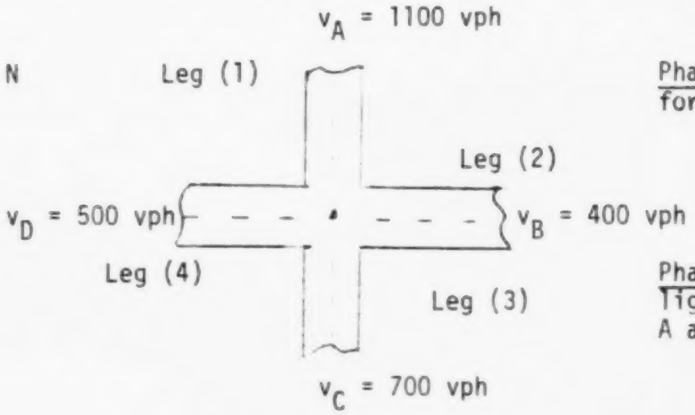
(5) If the (v/c)' determined in the previous step is less than "1," the intersection is able to accommodate traffic at the specified Level of Service (i.e., Level of Service E) or better.

(6) Apportion the difference between "1" and the intersection's (v/c)' (estimated in Step 4) among each phase at the intersection in proportion to the maximum (v/c)' estimated for that phase to determine how the excess G/C_y is apportioned among phases.

(7) Add the results of Steps (3) and (6). The sum is the computed G/C_y for each approach to an intersection having a traffic actuated signal.

This seven-step procedure is illustrated for the intersection sketched on the following page.

Example. For four 1-lane approaches to an intersection having a two-phase cycle, what is the G/C_y for each approach given the volume demands shown in the sketch? Assume the unimpeded capacity is 2000 vph/lane.



Phase I: Green light for approaches D and B.

Phase II: Green light for approaches A and C.

(1) $c_A = c_B = c_C = c_D = 2000$ vph

(2) $(v/c)'_A = 1100/2000 = 0.55$

$(v/c)'_B = 400/2000 = 0.20$

$(v/c)'_C = 700/2000 = 0.35$

$(v/c)'_D = 500/2000 = 0.25$

(3) For Phase I, the highest $(v/c)'$ is $(v/c)'_D = 0.25$

For Phase II, the highest $(v/c)'$ is $(v/c)'_A = 0.55$

(4) Therefore, $(v/c)'$ for the intersection is $0.25 + 0.55 + 0.1 = 0.90$. The "0.1" is used to account for the time during which the signal is amber.

(5-6) For Phase I, excess $G/C_y = \left(\frac{.25}{.25+.55}\right)(1-.90) = .03$

For Phase II, excess $G/C_y = \left(\frac{.55}{.25+.55}\right)(1-.90) = .07$

(7) Therefore, for approaches A and C,

$(G/C_y)_{II} = 0.55 + .07 = \underline{0.62}$ and

for approaches B and D,

$(G/C_y)_I = 0.25 + .03 = \underline{0.28}$

After the green time to signal cycle ratio has been estimated, Equation (A18) can be used to estimate queue lengths occurring at each approach to the intersection. The excess emission intensity to be applied for the queue length L_{ij} in lane j at approach i may be estimated using Equation (A19).

$$q_{ij} = \left[\frac{\left(\overline{(EF)}_{ij} \right) \quad (1-G/C_y))}{60D} + \frac{0.5(EF)'_{ij} \, (1-G/C_y)_i}{60D} \right] \qquad \text{(A19)}$$

where q_{ij} = line source emission intensity to be applied over a queue length, L_{ij}, in lane j at intersection approach i, gm/sec-m;

$\overline{(EF)}_{ij}$ = average emission factor for acceleration and decelerating vehicles over the estimated queue length, gm/min-veh;

$\frac{1}{60}$ = conversion factor from min^{-1} to sec^{-1};

D = spacing between successive vehicle tailpipes in the queue, assumed to be 8 m/veh;

0.5 = constant denoting that the average vehicle in the queue is only there for 1/2 of the signal's red phase, dimensionless;

$(EF)'_{ij}$ = emission factor for idling vehicles in the queue, gm/min-veh;

G/C_y = green time to signal cycle ratio at approach i, dimensionless.

Tables A8 - A12 depict queue lengths, excess emission intensity over the queue length and emission intensity resulting from freely flowing vehicles at approach speeds of 15, 20, 25, 30 and 35 mph respectively. For lanes which are downstream from intersections, ordinarily the emission intensity associated with freely flowing traffic should suffice. The emission intensity values in Tables A8 - A12 are appropriate for a 1975 national average mix of light-duty vehicles, 20%

Table A8

THE EFFECT ON SOURCE STRENGTH OF SIGNAL CYCLE LENGTH,TRAFFIC DEMAND,GREEN TIME AND APPROACH SPEED

APPROACH SPEED : 15 MPH

		G/CY = .2			G/CY = .3			G/CY = .4			G/CY = .5			G/CY = .6			G/CY = .7			G/CY = .8		
SC	TD	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI
60	2	21.3	.0155	.0025	18.7	.0136	.0025	16.0	.0116	.0025	13.3	.0097	.0025	10.7	.0077	.0025	8.0	.0058	.0025	5.3	.0039	.0025
60	4	42.7	.0179	.0051	37.3	.0159	.0051	32.0	.0136	.0051	26.7	.0114	.0051	21.3	.0091	.0051	16.0	.0068	.0051	10.7	.0045	.0051
60	6				56.0	.0166	.0076	48.0	.0148	.0076	40.0	.0131	.0076	32.0	.0104	.0076	24.0	.0078	.0076	16.0	.0052	.0076
60	8							64.0	.0150	.0101	53.3	.0133	.0101	42.7	.0115	.0101	32.0	.0088	.0101	21.3	.0059	.0101
60	10										66.7	.0135	.0127	53.3	.0117	.0127	40.0	.0099	.0127	26.7	.0066	.0127
60	12													64.0	.0118	.0152	48.0	.0100	.0152	32.0	.0072	.0152
60	14																56.0	.0102	.0177	37.3	.0079	.0177
60	16																			42.7	.0083	.0203
80	2	28.4	.0155	.0025	24.9	.0136	.0025	21.3	.0116	.0025	17.8	.0097	.0025	14.2	.0077	.0025	10.7	.0058	.0025	7.1	.0038	.0025
80	4	56.9	.0168	.0051	49.8	.0152	.0051	42.7	.0139	.0051	35.6	.0114	.0051	28.4	.0091	.0051	21.3	.0068	.0051	14.2	.0045	.0051
80	6				74.7	.0153	.0076	64.0	.0137	.0076	53.3	.0120	.0076	42.7	.0102	.0076	32.0	.0078	.0076	21.3	.0052	.0076
80	8							85.3	.0137	.0101	71.1	.0121	.0101	56.9	.0104	.0101	42.7	.0086	.0101	28.4	.0059	.0101
80	10										88.9	.0122	.0127	71.1	.0105	.0127	53.3	.0088	.0127	35.6	.0066	.0127
80	12													85.3	.0105	.0152	64.0	.0089	.0152	42.7	.0070	.0152
80	14																74.7	.0089	.0177	49.8	.0072	.0177
80	16																			56.9	.0072	.0203
100	2	35.6	.0155	.0025	31.1	.0136	.0025	26.7	.0116	.0025	22.2	.0097	.0025	17.8	.0077	.0025	13.3	.0058	.0025	8.9	.0039	.0025
100	4	71.1	.0161	.0051	62.2	.0145	.0051	53.3	.0128	.0051	44.4	.0111	.0051	35.6	.0091	.0051	26.7	.0068	.0051	17.8	.0045	.0051
100	6				93.3	.0145	.0076	80.0	.0129	.0076	66.7	.0113	.0076	53.3	.0096	.0076	40.0	.0078	.0076	26.7	.0052	.0076
100	8							106.7	.0129	.0101	88.9	.0113	.0101	71.1	.0097	.0101	53.3	.0080	.0101	35.6	.0059	.0101
100	10										111.1	.0113	.0127	88.9	.0097	.0127	66.7	.0081	.0127	44.4	.0063	.0127
100	12													106.7	.0097	.0152	80.0	.0081	.0152	53.3	.0064	.0152
100	14																93.3	.0081	.0177	62.2	.0065	.0177
100	16																			71.1	.0065	.0203
120	2	42.7	.0154	.0025	37.3	.0136	.0025	32.0	.0116	.0025	26.7	.0097	.0025	21.3	.0077	.0025	16.0	.0058	.0025	10.7	.0039	.0025
120	4	85.3	.0156	.0051	74.7	.0139	.0051	64.0	.0123	.0051	53.3	.0107	.0051	42.7	.0090	.0051	32.0	.0068	.0051	21.3	.0045	.0051
120	6				112.0	.0140	.0076	96.0	.0124	.0076	80.0	.0108	.0076	64.0	.0091	.0076	48.0	.0074	.0076	32.0	.0052	.0076
120	8							128.0	.0124	.0101	106.7	.0108	.0101	85.3	.0092	.0101	64.0	.0075	.0101	42.7	.0058	.0101
120	10										133.3	.0108	.0127	106.7	.0092	.0127	80.0	.0076	.0127	53.3	.0059	.0127
120	12													128.0	.0092	.0152	96.0	.0076	.0152	64.0	.0059	.0152
120	14																112.0	.0076	.0177	74.7	.0059	.0177
120	16																			85.3	.0060	.0203
140	2	49.8	.0151	.0025	43.6	.0134	.0025	37.3	.0116	.0025	31.1	.0097	.0025	24.9	.0077	.0025	18.7	.0058	.0025	12.4	.0039	.0025
140	4	99.6	.0152	.0051	87.1	.0136	.0051	74.7	.0120	.0051	62.2	.0103	.0051	49.8	.0087	.0051	37.3	.0068	.0051	24.9	.0045	.0051
140	6				130.7	.0136	.0076	112.0	.0120	.0076	93.3	.0104	.0076	74.7	.0088	.0076	56.0	.0071	.0076	37.3	.0052	.0076
140	8							149.3	.0120	.0101	124.4	.0104	.0101	99.6	.0088	.0101	74.7	.0072	.0101	49.8	.0055	.0101
140	10										155.6	.0104	.0127	124.4	.0088	.0127	93.3	.0072	.0127	62.2	.0055	.0127
140	12													149.3	.0088	.0152	112.0	.0072	.0152	74.7	.0056	.0152
140	14																130.7	.0072	.0177	87.1	.0056	.0177
140	16																			99.6	.0056	.0203

Table A8 continued

160	2	56.9	.0148	.0025	49.8	.0132	.0025	42.7	.0115	.0025	35.6	.0097	.0025	28.4	.0077	.0025	21.3	.0058	.0025	14.2	.0039	.0025
160	4	113.8	.0149	.0051	99.6	.0133	.0051	85.3	.0117	.0051	71.1	.0101	.0051	56.9	.0084	.0051	42.7	.0067	.0051	28.4	.0045	.0051
160	6				149.3	.0133	.0076	128.0	.0117	.0076	106.7	.0101	.0076	85.3	.0085	.0076	64.0	.0068	.0076	42.7	.0051	.0076
160	8							170.7	.0117	.0101	142.2	.0101	.0101	113.8	.0085	.0101	85.3	.0069	.0101	56.9	.0052	.0101
160	10										177.8	.0101	.0127	142.2	.0085	.0127	106.7	.0069	.0127	71.1	.0053	.0127
160	12													170.7	.0085	.0152	128.0	.0069	.0152	85.3	.0053	.0152
160	14																149.3	.0069	.0177	99.6	.0053	.0177
160	16																			113.8	.0053	.0203
180	2	64.0	.0146	.0025	56.0	.0130	.0025	48.0	.0113	.0025	40.0	.0097	.0025	32.0	.0077	.0025	24.0	.0058	.0025	16.0	.0039	.0025
180	4	128.0	.0147	.0051	112.0	.0131	.0051	96.0	.0114	.0051	80.0	.0098	.0051	64.0	.0082	.0051	48.0	.0065	.0051	32.0	.0045	.0051
180	6				168.0	.0131	.0076	144.0	.0115	.0076	120.0	.0099	.0076	96.0	.0082	.0076	72.0	.0066	.0076	48.0	.0049	.0076
180	8							192.0	.0115	.0101	160.0	.0099	.0101	128.0	.0083	.0101	96.0	.0066	.0101	64.0	.0050	.0101
180	10										200.0	.0099	.0127	160.0	.0083	.0127	120.0	.0067	.0127	80.0	.0050	.0127
180	12													192.0	.0083	.0152	144.0	.0067	.0152	96.0	.0050	.0152
180	14																168.0	.0067	.0177	112.0	.0051	.0177
180	16																			128.0	.0051	.0203
200	2	71.1	.0144	.0025	62.2	.0128	.0025	53.3	.0112	.0025	44.4	.0096	.0025	35.6	.0077	.0025	26.7	.0058	.0025	17.8	.0037	.0025
200	4	142.2	.0146	.0051	124.4	.0129	.0051	106.7	.0113	.0051	88.9	.0097	.0051	71.1	.0080	.0051	53.3	.0064	.0051	35.6	.0045	.0051
200	6				186.7	.0129	.0076	160.0	.0113	.0076	133.3	.0097	.0076	106.7	.0081	.0076	80.0	.0065	.0076	53.3	.0048	.0076
200	8							213.3	.0113	.0101	177.8	.0097	.0101	142.2	.0081	.0101	106.7	.0065	.0101	71.1	.0048	.0101
200	10										222.2	.0097	.0127	177.8	.0081	.0127	133.3	.0065	.0127	88.9	.0049	.0127
200	12													213.3	.0081	.0152	160.0	.0065	.0152	106.7	.0049	.0152
200	14																186.7	.0065	.0177	124.4	.0049	.0177
200	16																			142.2	.0049	.0203

Table A9

THE EFFECT ON SOURCE STRENGTH OF SIGNAL CYCLE LENGTH,TRAFFIC DEMAND,GREEN TIME AND APPROACH SPEED

APPROACH SPEED : 20 MPH

		G/CY = .2			G/CY = .3			G/CY = .4			G/CY = .5			G/CY = .6			G/CY = .7			G/CY = .8		
SCL	TD	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI
60	2	21.3	.0162	.0019	18.7	.0141	.0019	16.0	.0121	.0019	13.3	.0101	.0019	10.7	.0081	.0019	8.0	.0061	.0019	5.3	.0040	.0019
60	4	42.7	.0191	.0037	37.3	.0171	.0037	32.0	.0146	.0037	26.7	.0122	.0037	21.3	.0098	.0037	16.0	.0073	.0037	10.7	.0049	.0037
60	6				56.0	.0181	.0056	48.0	.0162	.0056	40.0	.0142	.0056	32.0	.0114	.0056	24.0	.0086	.0056	16.0	.0057	.0056
60	8							64.0	.0167	.0075	53.3	.0148	.0075	42.7	.0127	.0075	32.0	.0098	.0075	21.3	.0066	.0075
60	10										66.7	.0152	.0094	53.3	.0132	.0094	40.0	.0110	.0094	26.7	.0074	.0094
60	12													64.0	.0135	.0112	48.0	.0114	.0112	32.0	.0082	.0112
60	14																56.0	.0117	.0131	37.3	.0091	.0131
60	16																			42.7	.0095	.0150
80	2	28.4	.0162	.0019	24.9	.0141	.0019	21.3	.0121	.0019	17.8	.0101	.0019	14.2	.0081	.0019	10.7	.0061	.0019	7.1	.0040	.0019
80	4	56.9	.0180	.0037	49.8	.0162	.0037	42.7	.0143	.0037	35.6	.0122	.0037	28.4	.0098	.0037	21.3	.0073	.0037	14.2	.0049	.0037
80	6				74.7	.0167	.0056	64.0	.0149	.0056	53.3	.0131	.0056	42.7	.0111	.0056	32.0	.0086	.0056	21.3	.0057	.0056
80	8							85.3	.0152	.0075	71.1	.0135	.0075	56.9	.0116	.0075	42.7	.0095	.0075	28.4	.0066	.0075
80	10										88.9	.0136	.0094	71.1	.0119	.0094	53.3	.0099	.0094	35.6	.0074	.0094
80	12													85.3	.0120	.0112	64.0	.0101	.0112	42.7	.0079	.0112
80	14																74.7	.0103	.0131	49.8	.0082	.0131
80	16																			56.9	.0084	.0150
100	2	35.6	.0162	.0019	31.1	.0141	.0019	26.7	.0121	.0019	22.2	.0101	.0019	17.8	.0081	.0019	13.3	.0061	.0019	8.9	.0040	.0019
100	4	71.1	.0172	.0037	62.2	.0154	.0037	53.3	.0137	.0037	44.4	.0119	.0037	35.6	.0098	.0037	26.7	.0073	.0037	17.8	.0049	.0037
100	6				93.3	.0157	.0056	80.0	.0140	.0056	66.7	.0123	.0056	53.3	.0105	.0056	40.0	.0085	.0056	26.7	.0057	.0056
100	8							106.7	.0142	.0075	88.9	.0125	.0075	71.1	.0108	.0075	53.3	.0089	.0075	35.6	.0066	.0075
100	10										111.1	.0126	.0094	88.9	.0109	.0094	66.7	.0091	.0094	44.4	.0071	.0094
100	12													106.7	.0110	.0112	80.0	.0092	.0112	53.3	.0073	.0112
100	14																93.3	.0093	.0131	62.2	.0074	.0131
100	16																			71.1	.0076	.0150
120	2	42.7	.0160	.0019	37.3	.0141	.0019	32.0	.0121	.0019	26.7	.0101	.0019	21.3	.0081	.0019	16.0	.0061	.0019	10.7	.0040	.0019
120	4	85.3	.0165	.0037	74.7	.0149	.0037	64.0	.0132	.0037	53.3	.0114	.0037	42.7	.0096	.0037	32.0	.0073	.0037	21.3	.0049	.0037
120	6				112.0	.0150	.0056	96.0	.0134	.0056	80.0	.0117	.0056	64.0	.0100	.0056	48.0	.0081	.0056	32.0	.0057	.0056
120	8							128.0	.0134	.0075	106.7	.0118	.0075	85.3	.0101	.0075	64.0	.0084	.0075	42.7	.0064	.0075
120	10										133.3	.0118	.0094	106.7	.0102	.0094	80.0	.0085	.0094	53.3	.0066	.0094
120	12													128.0	.0102	.0112	96.0	.0086	.0112	64.0	.0068	.0112
120	14																112.0	.0086	.0131	74.7	.0069	.0131
120	16																			85.3	.0069	.0150
140	2	49.8	.0157	.0019	43.6	.0139	.0019	37.3	.0121	.0019	31.1	.0101	.0019	24.9	.0081	.0019	18.7	.0061	.0019	12.4	.0040	.0019
140	4	99.6	.0160	.0037	87.1	.0144	.0037	74.7	.0127	.0037	62.2	.0110	.0037	49.8	.0093	.0037	37.3	.0073	.0037	24.9	.0049	.0037
140	6				130.7	.0145	.0056	112.0	.0129	.0056	93.3	.0112	.0056	74.7	.0095	.0056	56.0	.0078	.0056	37.3	.0057	.0056
140	8							149.3	.0129	.0075	124.4	.0113	.0075	99.6	.0096	.0075	74.7	.0079	.0075	49.8	.0061	.0075
140	10										155.6	.0113	.0094	124.4	.0097	.0094	93.3	.0080	.0094	62.2	.0062	.0094
140	12													149.3	.0097	.0112	112.0	.0081	.0112	74.7	.0063	.0112
140	14																130.7	.0081	.0131	87.1	.0064	.0131
140	16																			99.6	.0064	.0150

Table A9 continued

160	2	56.9	.0154	.0019	49.8	.0137	.0019	42.7	.0120	.0019	35.6	.0101	.0019	28.4	.0081	.0019	21.3	.0061	.0019	14.2	.0040	.0019
160	4	113.8	.0157	.0037	99.6	.0140	.0037	85.3	.0124	.0037	71.1	.0107	.0037	56.9	.0090	.0037	42.7	.0072	.0037	28.4	.0049	.0037
160	6				149.3	.0141	.0056	128.0	.0125	.0056	106.7	.0108	.0056	85.3	.0092	.0056	64.0	.0075	.0056	42.7	.0056	.0056
160	8							170.7	.0125	.0075	142.2	.0109	.0075	113.8	.0093	.0075	85.3	.0076	.0075	56.9	.0058	.0075
160	10										177.8	.0109	.0094	142.2	.0093	.0094	106.7	.0076	.0094	71.1	.0059	.0094
160	12													170.7	.0093	.0112	128.0	.0077	.0112	85.3	.0060	.0112
160	14																149.3	.0077	.0131	99.6	.0060	.0131
160	16																			113.8	.0061	.0150
180	2	64.0	.0152	.0019	56.0	.0135	.0019	48.0	.0118	.0019	40.0	.0101	.0019	32.0	.0081	.0019	24.0	.0061	.0019	16.0	.0040	.0019
180	4	128.0	.0154	.0037	112.0	.0137	.0037	96.0	.0121	.0037	80.0	.0105	.0037	64.0	.0088	.0037	48.0	.0070	.0037	32.0	.0049	.0037
180	6				168.0	.0138	.0056	144.0	.0122	.0056	120.0	.0105	.0056	96.0	.0089	.0056	72.0	.0072	.0056	48.0	.0054	.0056
180	8							192.0	.0122	.0075	160.0	.0106	.0075	128.0	.0090	.0075	96.0	.0073	.0075	64.0	.0056	.0075
180	10										200.0	.0106	.0094	160.0	.0090	.0094	120.0	.0073	.0094	80.0	.0057	.0094
180	12													192.0	.0090	.0112	144.0	.0074	.0112	96.0	.0057	.0112
180	14																168.0	.0074	.0131	112.0	.0057	.0131
180	16																			128.0	.0058	.0150
200	2	71.1	.0150	.0019	62.2	.0133	.0019	53.3	.0116	.0019	44.4	.0099	.0019	35.6	.0081	.0019	26.7	.0061	.0019	17.8	.0040	.0019
200	4	142.2	.0151	.0037	124.4	.0135	.0037	106.7	.0119	.0037	88.9	.0102	.0037	71.1	.0086	.0037	53.3	.0068	.0037	35.6	.0049	.0037
200	6				186.7	.0135	.0056	160.0	.0119	.0056	133.3	.0103	.0056	106.7	.0087	.0056	80.0	.0070	.0056	53.3	.0052	.0056
200	8							213.3	.0119	.0075	177.8	.0103	.0075	142.2	.0087	.0075	106.7	.0071	.0075	71.1	.0054	.0075
200	10										222.2	.0103	.0094	177.8	.0087	.0094	133.3	.0071	.0094	88.9	.0054	.0094
200	12													213.3	.0087	.0112	160.0	.0071	.0112	106.7	.0055	.0112
200	14																186.7	.0071	.0131	124.4	.0055	.0131
200	16																			142.2	.0055	.0150

Table A10

THE EFFECT ON SOURCE STRENGTH OF SIGNAL CYCLE LENGTH,TRAFFIC DEMAND,GREEN TIME AND APPROACH SPEED

APPROACH SPEED I 25 MPH

		G/CY = .2			G/CY = .3			G/CY = .4			G/CY = .5			G/CY = .6			G/CY = .7			G/CY = .8		
SCL	TD	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI
60	2	21.3	.0164	.0014	18.7	.0143	.0014	16.0	.0123	.0014	13.3	.0102	.0014	10.7	.0082	.0014	8.0	.0061	.0014	5.3	.0041	.0014
60	4	42.7	.0197	.0029	37.3	.0175	.0029	32.0	.0150	.0029	26.7	.0125	.0029	21.3	.0100	.0029	16.0	.0075	.0029	10.7	.0050	.0029
60	6				56.0	.0191	.0043	48.0	.0169	.0043	40.0	.0147	.0043	32.0	.0118	.0043	24.0	.0088	.0043	16.0	.0059	.0043
60	8							64.0	.0179	.0057	53.3	.0157	.0057	42.7	.0133	.0057	32.0	.0102	.0057	21.3	.0068	.0057
60	10										66.7	.0164	.0072	53.3	.0141	.0072	40.0	.0115	.0072	26.7	.0077	.0072
60	12													64.0	.0147	.0086	48.0	.0121	.0086	32.0	.0086	.0086
60	14																56.0	.0127	.0100	37.3	.0095	.0100
60	16																			42.7	.0101	.0115
80	2	28.4	.0164	.0014	24.9	.0143	.0014	21.3	.0123	.0014	17.8	.0102	.0014	14.2	.0082	.0014	10.7	.0061	.0014	7.1	.0041	.0014
80	4	56.9	.0187	.0029	49.8	.0168	.0029	42.7	.0148	.0029	35.6	.0125	.0029	28.4	.0100	.0029	21.3	.0075	.0029	14.2	.0050	.0029
80	6				74.7	.0178	.0043	64.0	.0158	.0043	53.3	.0138	.0043	42.7	.0116	.0043	32.0	.0088	.0043	21.3	.0059	.0043
80	8							85.3	.0164	.0057	71.1	.0145	.0057	56.9	.0123	.0057	42.7	.0103	.0057	28.4	.0068	.0057
80	10										88.9	.0149	.0072	71.1	.0129	.0072	53.3	.0106	.0072	35.6	.0077	.0072
80	12													85.3	.0132	.0086	64.0	.0110	.0086	42.7	.0084	.0086
80	14																74.7	.0114	.0100	49.8	.0088	.0100
80	16																			56.9	.0091	.0115
100	2	35.6	.0164	.0014	31.1	.0143	.0014	26.7	.0123	.0014	22.2	.0102	.0014	17.8	.0082	.0014	13.3	.0061	.0014	8.9	.0041	.0014
100	4	71.1	.0180	.0029	62.2	.0161	.0029	53.3	.0142	.0029	44.4	.0122	.0029	35.6	.0100	.0029	26.7	.0075	.0029	17.8	.0050	.0029
100	6				93.3	.0168	.0043	80.0	.0150	.0043	66.7	.0131	.0043	53.3	.0110	.0043	40.0	.0088	.0043	26.7	.0059	.0043
100	8							106.7	.0153	.0057	88.9	.0135	.0057	71.1	.0116	.0057	53.3	.0094	.0057	35.6	.0068	.0057
100	10										111.1	.0138	.0072	88.9	.0119	.0072	66.7	.0099	.0072	44.4	.0074	.0072
100	12													106.7	.0121	.0086	80.0	.0102	.0086	53.3	.0078	.0086
100	14																93.3	.0104	.0100	62.2	.0081	.0100
100	16																			71.1	.0084	.0115
120	2	42.7	.0163	.0014	37.3	.0143	.0014	32.0	.0123	.0014	26.7	.0102	.0014	21.3	.0082	.0014	16.0	.0061	.0014	10.7	.0041	.0014
120	4	85.3	.0173	.0029	74.7	.0156	.0029	64.0	.0138	.0029	53.3	.0119	.0029	42.7	.0099	.0029	32.0	.0075	.0029	21.3	.0050	.0029
120	6				112.0	.0160	.0043	96.0	.0143	.0043	80.0	.0125	.0043	64.0	.0106	.0043	48.0	.0085	.0043	32.0	.0059	.0043
120	8							128.0	.0145	.0057	106.7	.0128	.0057	85.3	.0109	.0057	64.0	.0090	.0057	42.7	.0067	.0057
120	10										133.3	.0129	.0072	106.7	.0112	.0072	80.0	.0093	.0072	53.3	.0071	.0072
120	12													128.0	.0113	.0086	96.0	.0095	.0086	64.0	.0074	.0086
120	14																112.0	.0096	.0100	74.7	.0076	.0100
120	16																			85.3	.0077	.0115
140	2	49.8	.0160	.0014	43.6	.0142	.0014	37.3	.0123	.0014	31.1	.0102	.0014	24.9	.0082	.0014	18.7	.0061	.0014	12.4	.0041	.0014
140	4	99.6	.0168	.0029	87.1	.0151	.0029	74.7	.0134	.0029	62.2	.0115	.0029	49.8	.0096	.0029	37.3	.0075	.0029	24.9	.0050	.0029
140	6				130.7	.0154	.0043	112.0	.0137	.0043	93.3	.0120	.0043	74.7	.0102	.0043	56.0	.0082	.0043	37.3	.0059	.0043
140	8							149.3	.0139	.0057	124.4	.0122	.0057	99.6	.0104	.0057	74.7	.0086	.0057	49.8	.0064	.0057
140	10										155.6	.0123	.0072	124.4	.0106	.0072	93.3	.0088	.0072	62.2	.0067	.0072
140	12													149.3	.0107	.0086	112.0	.0089	.0086	74.7	.0070	.0086
140	14																130.7	.0090	.0100	87.1	.0071	.0100
140	16																			99.6	.0072	.0115

Table A10 continued

160	2	56.9	.0158	.0014	49.8	.0140	.0014	42.7	.0122	.0014	35.6	.0102	.0014	28.4	.0082	.0014	21.3	.0061	.0014	14.2	.0041	.0014
160	4	113.8	.0164	.0029	99.6	.0147	.0029	85.3	.0130	.0029	71.1	.0112	.0029	56.9	.0094	.0029	42.7	.0074	.0029	28.4	.0050	.0029
160	6				149.3	.0149	.0043	128.0	.0133	.0043	106.7	.0116	.0043	85.3	.0098	.0043	64.0	.0079	.0043	42.7	.0058	.0043
160	8							170.7	.0134	.0057	142.2	.0117	.0057	113.8	.0100	.0057	85.3	.0082	.0057	56.9	.0062	.0057
160	10										177.8	.0118	.0072	142.2	.0101	.0072	106.7	.0084	.0072	71.1	.0064	.0072
160	12													170.7	.0102	.0086	128.0	.0085	.0086	85.3	.0066	.0086
160	14																149.3	.0085	.0100	99.6	.0067	.0100
160	16																			113.8	.0068	.0115
180	2	64.0	.0156	.0014	56.0	.0138	.0014	48.0	.0120	.0014	40.0	.0102	.0014	32.0	.0082	.0014	24.0	.0061	.0014	16.0	.0041	.0014
180	4	128.0	.0161	.0029	112.0	.0144	.0029	96.0	.0127	.0029	80.0	.0110	.0029	64.0	.0092	.0029	48.0	.0072	.0029	32.0	.0050	.0029
180	6				168.0	.0145	.0043	144.0	.0129	.0043	120.0	.0112	.0043	96.0	.0095	.0043	72.0	.0077	.0043	48.0	.0056	.0043
180	8							192.0	.0130	.0057	160.0	.0113	.0057	128.0	.0097	.0057	96.0	.0079	.0057	64.0	.0060	.0057
180	10										200.0	.0114	.0072	160.0	.0097	.0072	120.0	.0080	.0072	80.0	.0062	.0072
180	12													192.0	.0098	.0086	144.0	.0081	.0086	96.0	.0063	.0086
180	14																168.0	.0081	.0100	112.0	.0064	.0100
180	16																			128.0	.0065	.0115
200	2	71.1	.0154	.0014	62.2	.0137	.0014	53.3	.0119	.0014	44.4	.0101	.0014	35.6	.0082	.0014	26.7	.0061	.0014	17.8	.0041	.0014
200	4	142.2	.0158	.0029	124.4	.0141	.0029	106.7	.0125	.0029	88.9	.0108	.0029	71.1	.0090	.0029	53.3	.0071	.0029	35.6	.0050	.0029
200	6				186.7	.0142	.0043	160.0	.0126	.0043	133.3	.0110	.0043	106.7	.0093	.0043	80.0	.0075	.0043	53.3	.0055	.0043
200	8							213.3	.0126	.0057	177.8	.0110	.0057	142.2	.0094	.0057	106.7	.0077	.0057	71.1	.0058	.0057
200	10										222.2	.0110	.0072	177.8	.0094	.0072	133.3	.0078	.0072	88.9	.0060	.0072
200	12													213.3	.0094	.0086	160.0	.0078	.0086	106.7	.0061	.0086
200	14																186.7	.0078	.0100	124.4	.0061	.0130
200	16																			142.2	.0062	.0115

Table A11

THE EFFECT ON SOURCE STRENGTH OF SIGNAL CYCLE LNGTH,TRAFFIC DEMAND,GREEN TIME AND APPROACH SPEED

APPROACH SPEED : 30 MPH

SCL	TD	G/CY = .2			G/CY = .3			G/CY = .4			G/CY = .5			G/CY = .6			G/CY = .7			G/CY = .8		
		QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI
60	2	21.3	.0165	.0012	18.7	.0144	.0012	16.0	.0124	.0012	13.3	.0103	.0012	10.7	.0083	.0012	8.0	.0062	.0012	5.3	.0041	.0012
60	4	42.7	.0199	.0023	37.3	.0177	.0023	32.0	.0152	.0023	26.7	.0126	.0023	21.3	.0101	.0023	16.0	.0076	.0023	10.7	.0051	.0023
60	6				56.0	.0192	.0035	48.0	.0171	.0035	40.0	.0150	.0035	32.0	.0120	.0035	24.0	.0090	.0035	16.0	.0060	.0035
60	8							64.0	.0181	.0046	53.3	.0158	.0046	42.7	.0135	.0046	32.0	.0104	.0046	21.3	.0069	.0046
60	10										66.7	.0166	.0058	53.3	.0142	.0058	40.0	.0118	.0058	26.7	.0078	.0058
60	12													64.0	.0149	.0070	48.0	.0123	.0070	32.0	.0088	.0070
60	14																56.0	.0128	.0081	37.3	.0097	.0081
60	16																			42.7	.0103	.0093
80	2	28.4	.0165	.0012	24.9	.0144	.0012	21.3	.0124	.0012	17.8	.0103	.0012	14.2	.0083	.0012	10.7	.0062	.0012	7.1	.0041	.0012
80	4	56.9	.0188	.0023	49.8	.0169	.0023	42.7	.0150	.0023	35.6	.0126	.0023	28.4	.0101	.0023	21.3	.0076	.0023	14.2	.0051	.0023
80	6				74.7	.0180	.0035	64.0	.0160	.0035	53.3	.0139	.0035	42.7	.0118	.0035	32.0	.0090	.0035	21.3	.0060	.0035
80	8							85.3	.0168	.0046	71.1	.0147	.0046	56.9	.0124	.0046	42.7	.0102	.0046	28.4	.0069	.0046
80	10										88.9	.0154	.0058	71.1	.0131	.0058	53.3	.0107	.0058	35.6	.0078	.0058
80	12													85.3	.0136	.0070	64.0	.0112	.0070	42.7	.0086	.0070
80	14																74.7	.0116	.0081	49.8	.0089	.0081
80	16																			56.9	.0092	.0093
100	2	35.6	.0165	.0012	31.1	.0144	.0012	26.7	.0124	.0012	22.2	.0103	.0012	17.8	.0083	.0012	13.3	.0062	.0012	8.9	.0041	.0012
100	4	71.1	.0181	.0023	62.2	.0162	.0023	53.3	.0143	.0023	44.4	.0124	.0023	35.6	.0101	.0023	26.7	.0076	.0023	17.8	.0051	.0023
100	6				93.3	.0172	.0035	80.0	.0152	.0035	66.7	.0132	.0035	53.3	.0111	.0035	40.0	.0090	.0035	26.7	.0060	.0035
100	8							106.7	.0160	.0046	88.9	.0139	.0046	71.1	.0117	.0046	53.3	.0095	.0046	35.6	.0069	.0046
100	10										111.1	.0145	.0058	88.9	.0123	.0058	66.7	.0100	.0058	44.4	.0076	.0058
100	12													106.7	.0128	.0070	80.0	.0104	.0070	53.3	.0079	.0070
100	14																93.3	.0108	.0081	62.2	.0082	.0081
100	16																			71.1	.0085	.0093
120	2	42.7	.0164	.0012	37.3	.0144	.0012	32.0	.0124	.0012	26.7	.0103	.0012	21.3	.0083	.0012	16.0	.0062	.0012	10.7	.0041	.0012
120	4	85.3	.0176	.0023	74.7	.0157	.0023	64.0	.0138	.0023	53.3	.0119	.0023	42.7	.0100	.0023	32.0	.0076	.0023	21.3	.0051	.0023
120	6				112.0	.0166	.0035	96.0	.0147	.0035	80.0	.0127	.0035	64.0	.0106	.0035	48.0	.0085	.0035	32.0	.0060	.0035
120	8							128.0	.0153	.0046	106.7	.0133	.0046	85.3	.0112	.0046	64.0	.0090	.0046	42.7	.0068	.0046
120	10										133.3	.0138	.0058	106.7	.0117	.0058	80.0	.0095	.0058	53.3	.0071	.0058
120	12													128.0	.0121	.0070	96.0	.0099	.0070	64.0	.0074	.0070
120	14																112.0	.0102	.0081	74.7	.0077	.0081
120	16																			85.3	.0080	.0093
140	2	49.8	.0161	.0012	43.6	.0143	.0012	37.3	.0124	.0012	31.1	.0103	.0012	24.9	.0083	.0012	18.7	.0062	.0012	12.4	.0041	.0012
140	4	99.6	.0172	.0023	87.1	.0154	.0023	74.7	.0135	.0023	62.2	.0116	.0023	49.8	.0097	.0023	37.3	.0076	.0023	24.9	.0051	.0023
140	6				130.7	.0161	.0035	112.0	.0142	.0035	93.3	.0123	.0035	74.7	.0103	.0035	56.0	.0082	.0035	37.3	.0060	.0035
140	8							149.3	.0148	.0046	124.4	.0128	.0046	99.6	.0108	.0046	74.7	.0087	.0046	49.8	.0065	.0046
140	10										155.6	.0132	.0058	124.4	.0112	.0058	93.3	.0091	.0058	62.2	.0068	.0058
140	12													149.3	.0116	.0070	112.0	.0094	.0070	74.7	.0071	.0070
140	14																130.7	.0097	.0081	87.1	.0074	.0081
140	16																			99.6	.0076	.0093

Table A11 continued

160	2	56.9	.0158	.0012	49.8	.0141	.0012	42.7	.0123	.0012	35.6	.0103	.0012	28.4	.0083	.0012	21.3	.0062	.0012	14.2	.0041	.0012
160	4	113.8	.0169	.0023	99.6	.0151	.0023	85.3	.0132	.0023	71.1	.0113	.0023	56.9	.0094	.0023	42.7	.0075	.0023	28.4	.0051	.0023
160	6				149.3	.0157	.0035	128.0	.0139	.0035	106.7	.0120	.0035	85.3	.0100	.0035	64.0	.0080	.0035	42.7	.0059	.0035
160	8							170.7	.0143	.0046	142.2	.0124	.0046	113.8	.0105	.0046	85.3	.0084	.0046	56.9	.0062	.0046
160	10										177.8	.0127	.0058	142.2	.0108	.0058	106.7	.0088	.0058	71.1	.0065	.0058
160	12													170.7	.0111	.0070	128.0	.0091	.0070	85.3	.0068	.0070
160	14																149.3	.0093	.0081	99.6	.0071	.0081
160	16																			113.8	.0073	.0093
180	2	64.0	.0156	.0012	56.0	.0139	.0012	48.0	.0121	.0012	40.0	.0103	.0012	32.0	.0083	.0012	24.0	.0062	.0012	16.0	.0041	.0012
180	4	128.0	.0166	.0023	112.0	.0148	.0023	96.0	.0130	.0023	80.0	.0111	.0023	64.0	.0092	.0023	48.0	.0073	.0023	32.0	.0051	.0023
180	6				168.0	.0153	.0035	144.0	.0136	.0035	120.0	.0117	.0035	96.0	.0098	.0035	72.0	.0078	.0035	48.0	.0057	.0035
180	8							192.0	.0138	.0046	160.0	.0121	.0046	128.0	.0102	.0046	96.0	.0082	.0046	64.0	.0060	.0046
180	10										200.0	.0122	.0058	160.0	.0105	.0058	120.0	.0085	.0058	80.0	.0063	.0058
180	12													192.0	.0106	.0070	144.0	.0088	.0070	96.0	.0066	.0070
180	14																168.0	.0089	.0081	114.0	.0068	.0081
180	16																			126.0	.0070	.0093
200	2	71.1	.0155	.0012	62.2	.0137	.0012	53.3	.0120	.0012	44.4	.0102	.0012	35.6	.0083	.0012	26.7	.0062	.0012	17.8	.0041	.0012
200	4	142.2	.0164	.0023	124.4	.0146	.0023	106.7	.0128	.0023	88.9	.0109	.0023	71.1	.0091	.0023	53.3	.0072	.0023	35.6	.0051	.0023
200	6				186.7	.0150	.0035	160.0	.0133	.0035	133.3	.0115	.0035	106.7	.0096	.0035	80.0	.0076	.0035	53.3	.0056	.0035
200	8							213.3	.0134	.0046	177.8	.0118	.0046	142.2	.0100	.0046	106.7	.0080	.0046	71.1	.0059	.0046
200	10										222.2	.0118	.0058	177.8	.0102	.0058	133.3	.0083	.0058	88.9	.0061	.0058
200	12													213.3	.0102	.0070	160.0	.0085	.0070	106.7	.0064	.0070
200	14																186.7	.0086	.0081	124.4	.0066	.0081
200	16																			142.2	.0068	.0093

Table A12

THE EFFECT ON SOURCE STRENGTH OF SIGNAL CYCLE LENGTH,TRAFFIC DEMAND,GREEN TIME AND APPROACH SPEED

APPROACH SPEED : 35 MPH

SCL	TD	G/CY = .2			G/CY = .3			G/CY = .4			G/CY = .5			G/CY = .6			G/CY = .7			G/CY = .8		
		QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI	QLNTH	FLSI	ILSI
60	2	21.3	.0166	.0010	18.7	.0145	.0010	16.0	.0124	.0010	13.3	.0104	.0010	10.7	.0083	.0010	8.0	.0062	.0010	5.3	.0041	.0010
60	4	42.7	.0202	.0020	37.3	.0178	.0020	32.0	.0153	.0020	26.7	.0127	.0020	21.3	.0102	.0020	16.0	.0076	.0020	10.7	.0051	.0020
60	6				56.0	.0196	.0029	48.0	.0174	.0029	40.0	.0151	.0029	32.0	.0121	.0029	24.0	.0091	.0029	16.0	.0060	.0029
60	8							64.0	.0186	.0039	53.3	.0162	.0039	42.7	.0138	.0039	32.0	.0105	.0039	21.3	.0070	.0039
60	10										66.7	.0172	.0049	53.3	.0146	.0049	40.0	.0119	.0049	26.7	.0079	.0049
60	12													64.0	.0154	.0059	48.0	.0126	.0059	32.0	.0089	.0059
60	14																56.0	.0132	.0069	37.3	.0098	.0069
60	16																			42.7	.0106	.0079
80	2	28.4	.0166	.0010	24.9	.0145	.0010	21.3	.0124	.0010	17.8	.0104	.0010	14.2	.0083	.0010	10.7	.0062	.0010	7.1	.0041	.0010
80	4	56.9	.0191	.0020	49.8	.0171	.0020	42.7	.0151	.0020	35.6	.0127	.0020	28.4	.0102	.0020	21.3	.0076	.0020	14.2	.0051	.0020
80	6				74.7	.0185	.0029	64.0	.0163	.0029	53.3	.0141	.0029	42.7	.0119	.0029	32.0	.0091	.0029	21.3	.0060	.0029
80	8							85.3	.0174	.0039	71.1	.0151	.0039	56.9	.0127	.0039	42.7	.0103	.0039	28.4	.0070	.0039
80	10										88.9	.0159	.0049	71.1	.0135	.0049	53.3	.0109	.0049	35.6	.0079	.0049
80	12													85.3	.0142	.0059	64.0	.0115	.0059	42.7	.0087	.0059
80	14																74.7	.0121	.0069	49.8	.0091	.0069
80	16																			56.9	.0095	.0079
100	2	35.6	.0166	.0010	31.1	.0145	.0010	26.7	.0124	.0010	22.2	.0104	.0010	17.8	.0083	.0010	13.3	.0062	.0010	8.9	.0041	.0010
100	4	71.1	.0185	.0020	62.2	.0165	.0020	53.3	.0145	.0020	44.4	.0125	.0020	35.6	.0102	.0020	26.7	.0076	.0020	17.8	.0051	.0020
100	6				93.3	.0177	.0029	80.0	.0156	.0029	66.7	.0135	.0029	53.3	.0113	.0029	40.0	.0091	.0029	26.7	.0060	.0029
100	8							106.7	.0165	.0039	88.9	.0144	.0039	71.1	.0121	.0039	53.3	.0097	.0039	35.6	.0070	.0039
100	10										111.1	.0151	.0049	88.9	.0128	.0049	66.7	.0103	.0049	44.4	.0077	.0049
100	12													106.7	.0133	.0059	80.0	.0108	.0059	53.3	.0081	.0059
100	14																93.3	.0113	.0069	62.2	.0085	.0069
100	16																			71.1	.0089	.0079
120	2	42.7	.0165	.0010	37.3	.0145	.0010	32.0	.0124	.0010	26.7	.0104	.0010	21.3	.0083	.0010	16.0	.0062	.0010	10.7	.0041	.0010
120	4	85.3	.0180	.0020	74.7	.0160	.0020	64.0	.0141	.0020	53.3	.0121	.0020	42.7	.0101	.0020	32.0	.0076	.0020	21.3	.0051	.0020
120	6				112.0	.0171	.0029	96.0	.0151	.0029	80.0	.0130	.0029	64.0	.0109	.0029	48.0	.0087	.0029	32.0	.0060	.0029
120	8							128.0	.0159	.0039	106.7	.0138	.0039	85.3	.0116	.0039	64.0	.0093	.0039	42.7	.0069	.0039
120	10										133.3	.0144	.0049	106.7	.0122	.0049	80.0	.0098	.0049	53.3	.0073	.0049
120	12													128.0	.0127	.0059	96.0	.0103	.0059	64.0	.0077	.0059
120	14																112.0	.0107	.0069	74.7	.0080	.0069
120	16																			85.3	.0084	.0079
140	2	49.8	.0162	.0010	43.6	.0144	.0010	37.3	.0124	.0010	31.1	.0104	.0010	24.9	.0083	.0010	18.7	.0062	.0010	12.4	.0041	.0010
140	4	99.6	.0176	.0020	87.1	.0157	.0020	74.7	.0138	.0020	62.2	.0118	.0020	49.8	.0098	.0020	37.3	.0076	.0020	24.9	.0051	.0020
140	6				130.7	.0166	.0029	112.0	.0147	.0029	93.3	.0127	.0029	74.7	.0106	.0029	56.0	.0084	.0029	37.3	.0060	.0029
140	8							149.3	.0153	.0039	124.4	.0133	.0039	99.6	.0112	.0039	74.7	.0090	.0039	49.8	.0066	.0039
140	10										155.6	.0138	.0049	124.4	.0117	.0049	93.3	.0095	.0049	62.2	.0070	.0049
140	12													149.3	.0121	.0059	112.0	.0099	.0059	74.7	.0074	.0059
140	14																130.7	.0102	.0069	87.1	.0077	.0069
140	16																			99.6	.0080	.0079

Table A12 continued

160	2	56.9	.0160	.0010	49.8	.0142	.0010	42.7	.0124	.0010	35.6	.0104	.0010	28.4	.0083	.0010	21.3	.0062	.0010	14.2	.0041	.0010
160	4	113.8	.0173	.0020	99.6	.0154	.0020	85.3	.0135	.0020	71.1	.0115	.0020	56.9	.0096	.0020	42.7	.0076	.0020	28.4	.0051	.0020
160	6				149.3	.0162	.0029	128.0	.0143	.0029	106.7	.0123	.0029	85.3	.0103	.0029	64.0	.0082	.0029	42.7	.0060	.0029
160	8							170.7	.0149	.0039	142.2	.0129	.0039	113.8	.0109	.0039	85.3	.0087	.0039	56.9	.0064	.0039
160	10										177.8	.0133	.0049	142.2	.0113	.0049	106.7	.0091	.0049	71.1	.0067	.0049
160	12													170.7	.0117	.0059	128.0	.0095	.0059	85.3	.0071	.0059
160	14																149.3	.0098	.0069	99.6	.0074	.0069
160	16																			113.8	.0077	.0079
180	2	64.0	.0158	.0010	56.0	.0140	.0010	48.0	.0122	.0010	40.0	.0104	.0010	32.0	.0083	.0010	24.0	.0062	.0010	16.0	.0041	.0010
180	4	128.0	.0170	.0020	112.0	.0152	.0020	96.0	.0133	.0020	80.0	.0113	.0020	64.0	.0094	.0020	48.0	.0074	.0020	32.0	.0051	.0020
180	6				168.0	.0159	.0029	144.0	.0140	.0029	120.0	.0121	.0029	96.0	.0101	.0029	72.0	.0080	.0029	48.0	.0058	.0029
180	8							192.0	.0144	.0039	160.0	.0126	.0039	128.0	.0106	.0039	96.0	.0085	.0039	64.0	.0062	.0039
180	10										200.0	.0129	.0049	160.0	.0110	.0049	120.0	.0089	.0049	80.0	.0065	.0049
180	12													192.0	.0112	.0059	144.0	.0092	.0059	96.0	.0069	.0059
180	14																168.0	.0095	.0069	112.0	.0072	.0069
180	16																			128.0	.0074	.0079
200	2	71.1	.0156	.0010	62.2	.0139	.0010	53.3	.0121	.0010	44.4	.0102	.0010	35.6	.0083	.0010	26.7	.0062	.0010	17.8	.0041	.0010
200	4	142.2	.0167	.0020	124.4	.0149	.0020	106.7	.0131	.0020	88.9	.0112	.0020	71.1	.0092	.0020	53.3	.0073	.0020	35.6	.0051	.0020
200	6				186.7	.0155	.0029	160.0	.0137	.0029	133.3	.0118	.0029	106.7	.0099	.0029	80.0	.0078	.0029	53.3	.0057	.0029
200	8							213.3	.0140	.0039	177.8	.0123	.0039	142.2	.0103	.0039	106.7	.0083	.0039	71.1	.0060	.0039
200	10										222.2	.0124	.0049	177.8	.0107	.0049	133.3	.0086	.0049	88.9	.0064	.0049
200	12													213.3	.0108	.0059	160.0	.0089	.0059	106.7	.0067	.0059
200	14																186.7	.0091	.0069	124.4	.0069	.0069
200	16																			142.2	.0071	.0079

of which are assumed to be operating from a cold start in ambient temperatures ranging from 68°-86°F. For different years, vehicle mixes, percentages of cold starts, procedures similar to those described in Section 4.4 should be followed to derive correction factors which can be applied to the emission intensities appearing in Tables A8 - A12. For ambient temperature ranges outside of the range for which Tables A8 - A12 apply, Section 4.4 or Supplement Number 5 to AP-42[3] should be used to derive correction factors as needed. Referring to Tables A8 - A12, the column labeled SCL is the signal cycle length in seconds. TD is the traffic demand in hundreds of vehicles per hour (i.e., TD = 2 is equivalent to 200 vph). QLNTH is the average queue length forming during the red phase, in meters. FLSI is the "finite line source intensity" attributable to idling, accelerating and decelerating vehicles (gm/sec-m) and is applied only over the queue length. ILSI is the infinite line source emission intensity attributed to cruising vehicles, gm/sec-m. The ILSI is applied over the queue length as well as upstream and downstream from the queue. To illustrate the use of Tables A8 - A12, the emission intensities and queue lengths appropriate for the intersection legs sketched on page A36 will be obtained. Assume, for illustrative purposes, that the approach speed for each of the intersection approaches is 25 mph and the signal cycle length is 100 seconds. Note that for approaches A and C, $G/C_y = 0.62$, and for approaches B and D, $G/C_y = 0.28$. Since the approach speeds are all assumed to be 25 mph, Table A10 applies. From Table A10, the following information is obtained.

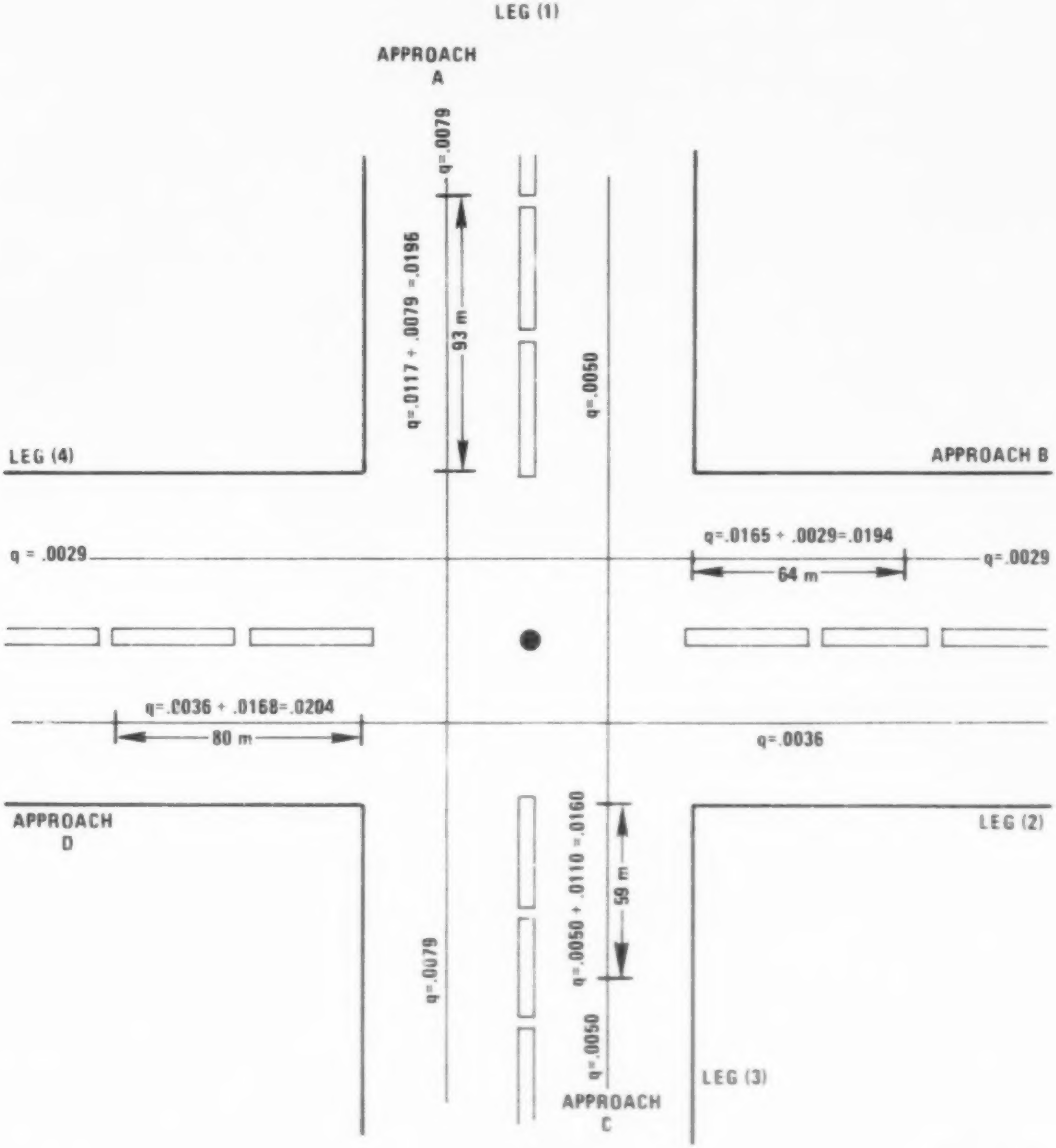
		G/C_y - .2			G/C_y = .3			G/C_y = .6			G/C_y = .7		
Intersection Approach	Traffic Demand (vph)	Queue Length (m)	Q_1	Q_2	L (m)	Q_1	Q_2	L (m)	Q_1	Q_2	L (m)	Q_1	Q_2
A	1000							88.9	.0119	.0072	66.7	.0099	.0072
	1200							106.7	.0121	.0086	80.0	.0102	.0086
B	400	71.1	.0180	.0029	62.2	.0161	.0029						
C	600							53.3	.0110	.0043	40.0	.0088	.0043
	800							71.1	.0116	.0057	53.3	.0094	.0057
D	400	71.1	.0180	.0029	62.2	.0161	.0029						
	600	106.7	.0185	.0043	93.3	.0168	.0043						

where Q_1 = excess emission intensity (gm/sec-m) exhibited over the queue length

Q_2 = emission intensity attributable to cruising traffic in the lane of interest (gm/sec-m), exhibited everywhere in the lane

$Q_1 + Q_2$ = total emission intensity (gm/sec-m) exhibited over the queue length

The information obtained from Table A10 may be interpolated to estimate queue lengths and emission intensities for each leg of the intersection shown below.


LEG (1)
APPROACH A
q=.0079
q=.0117 + .0079 =.0196
93 m
q=.0050
LEG (4)
APPROACH B
q = .0029
q=.0165 + .0029=.0194
64 m
q=.0029
q=.0036 + .0168=.0204
80 m
q=.0036
APPROACH D
LEG (2)
q=.0079
q=.0050 + .0110 =.0160
59 m
q=.0050
APPROACH C
LEG (3)

Frequently, it should be sufficient to use the traffic parameters in Tables A8 - A12 most closely corresponding to those which are observed. Thus, in the above example,

For Approach A, $G/C_y = .6$, $V = 1200$ vph, $L = 106.7$ m, the emission intensity over the finite queue = $Q_1 + Q_2 = .0207$ gm/sec-m, and the emission intensity elsewhere in the lane (Q_2) = .0086 gm/sec-m.

For Approach B, $G/C_y = .3$, $V = 400$ vph, $L = 62.2$ m, the emission intensity over the finite queue = $Q_1 + Q_2 = .0161 + 0029 = .0190$ gm/sec-m, and the emission intensity elsewhere in the lane (Q_2) = .0029 gm/sec-m.

For Approach C, $G/C_y = .6$, $V = 800$ vph, $L = 71.1$ m, the emission intensity over the finite queue = $Q_1 + Q_2 = .0116 + .0057 = .0174$ gm/sec-m, and the emission intensity elsewhere in the lane (Q_2) = .0057 gm/sec-m.

For Approach D, $G/C_y = .3$, $V = 600$ vph, $L = 93.3$ m, emission intensity over the finite queue = $Q_1 + Q_2 = .0168 + .0043 = .0211$ gm/sec-m, and the emission intensity elsewhere in the lane (Q_2) = .0043 gm/sec-m.

The foregoing discussion of estimating emissions at signalized intersections has ignored the impact of good signal progression by assuming that vehicles are equally likely to arrive at an intersection during red and green phases. Good signal progression, however, could result in a greater proportion of vehicles arriving during the green phase than would otherwise occur. In such a case, the excess emissions due to idling and acceleration/deceleration would be less, and would occur over a shorter queue length. To illustrate the impact such signal progression would have, suppose the traffic signals upstream from approaches A-D in the previous example were coordinated in such a way that 80 percent of the traffic arriving at the intersection does so when the light is green. Considering only Approach A, this means that 20 percent of the 1200 vph arrive during the red and amber phases rather than the 40 percent which would occur if traffic arrived uniformly and G/C_y were 0.6. Hence, from Equation (A18) the queue length L would be

$$L = \frac{(.2)(1200)(8)}{36} = 53 \text{ m} \qquad \text{(A18)}$$

where the "0.2" is substituted for $(1-G/C_y)$. In other words, this is equivalent to setting G/C_y equal to 0.8 with uncoordinated signals. Therefore, one can account for good signal progression in estimating the infinite and finite line source emission intensities by using the information for $G/C_y = 0.8$ in Table A10. Thus, the emission intensity over the 53 meter queue would become $Q_1 + Q_2 = .0078 + .0086 = 0164$ gm/sec-m and the emission intensity elsewhere would be .0086 gm/sec-m.

The procedure for estimating emissions at non-signalized intersections differs from that at signalized intersections, because queuing may occur continuously. Further, traffic is more likely characterized by stopping and starting motions as traffic moves up position by position in the queue. The average length of a queue accumulating during an entire hour (i.e., not just during the red phase of a traffic signal) may be obtained from queueing theory using Equation (A20).[9]

$$L_{ij} = \left[\frac{(v_{ij})^2}{c_{ij}\,(c_{ij} - v_{ij})}\right] D \qquad \text{(A20)}$$

where L_{ij} = average queue length in lane j at approach i, m;

v_{ij} = traffic volume demand in lane j, approach i, vph;

c_{ij} = approach capacity for lane j at approach i, vph;

D = spacing assumed between vehicle tailpipes, m/veh.

Emission intensity over the queue length is given by Equation (A21).

$$q_{ij} = (EF)_{ij}/60D \qquad \text{(A21)}$$

where $(EF)_{ij}$ = emission factor for stop-and-start traffic having an average speed approaching 0 mph, gm/min-veh

D = spacing between the tailpipes of vehicles in the queue, m/veh

1/60 = conversion from $\min^{-1}$ to $\sec^{-1}$

q_{ij} = emission intensity in lane j at approach i, gm/sec-m.

The impact of accelerating and decelerating vehicles would occur over a distance immediately downstream and upstream from the queue respectively. This existence may be estimated using Equation (A22).

$$\text{Distance} = \left|\frac{(\text{Final Velocity})^2 - (\text{Initial Velocity})^2}{(2)\ (\text{acceleration})}\right| \qquad \text{(A22)}$$

where Distance is in meters.

The velocity terms are in m/sec.

The acceleration term is in m/sec^2.

Emission intensity over the distance obtained with Equation (A22) may be approximated using Equation (A23).

$$q_{ij} = (1.036 \times 10^{-5})\ \overline{(EF)}_{ij}\ v_{ij}/S_{ij} \qquad \text{(A23)}$$

where

$\overline{(EF)}_{ij}$ = the average emission factor for a vehicle accelerating (decelerating) between initial and final velocities designated in Equation (A22), gm/min-veh

V_{ij} = traffic volume demand, vph

S_{ij} = approach speed x 1/2, mi/hr

The value of $\overline{(EF)}_{ij}$ could be obtained by using the Automobile Exhaust Emission Modal Analysis Model.[10] If it is not feasible to use the modal model, average trip speed emission factors similar to those used in Equation (A11) would have to suffice. This would result in underestimating emission intensity just downstream from the intersection approach. Equation (A11) may be used to estimate emission intensity at all other locations on the roadway.

REFERENCES

(1) *40 CFR 52*; "Approval and Promulgation of Implementation Plans--Review of Indirect Sources"; *Federal Register*; (July 9, 1974); p. 25292.

(2) U.S. EPA; Office of Federal Activities; *Guidelines for Review of Environmental Impact Statements*, Volume 1, Highway Projects; (September 1973).

(3) U.S. EPA; "Compilation of Air Pollutant Emission Factors" *Publication No. AP-42* (Second Edition) U.S. EPA, OAWP, OAQPS, Research Triangle Park, N.C. 27711 (Supplement No. 5, In Press).

(4) 40CFR 85; "1975 Federal Test Procedure"; *Federal Register*; *36*; No. 128; (July 2, 1971).

(5) Thayer, S. C. and J. D. Cook; "Vehicle Behavior in and Around Complex Sources and Related Complex Source Characteristics: Volume 6--Major Highways"; *EPA-450/3-74-003-f*; National Technical Information Service, Springfield, Va. 22161. (November 1973.)

(6) Tittemore, L. H., M. R. Birdsall, D. M. Hill and R. H. Hammond, "An Analysis of Urban Area Travel by Time of Day," *Report No. FH-11-7519*, U.S. DOT, FHA. Office of Planning, Wash., D. C. (1972).

(7) Mr. Robert Probst, Federal Highway Administration, Personal Communication.

(8) Highway Research Board. "Highway Capacity Manual 1965"; *Special Report 87*; NAS-NRC; Washington, D. C.; (1965).

(9) Hillier, F. S. and G. J. Lieberman; *Introduction to Operations Research*; Holden-Day, Inc., San Francisco, Ca.; Ch. 10; (1967).

(10) Kunselman, P., H. T. McAdams, C. J. Domke and M. Williams; Automobile Exhaust Emission Modal Analysis Model; *EPA-460/3-74-005*; January 1974); National Technical Information Service, Springfield, Va. 22161.

(11) Patterson, R. M. and F. A. Record; "Monitoring and Analysis of Traffic Characteristics at Oakbrook"; *EPA-450/3-74-058*; (Nov. 1974); National Technical Information Service, Springfield, Va. 22161.

(12) Leisch, J. E.; "Capacity Analysis Techniques for Design of Signalized Intersections"; *Public Roads 34*, Nos. 9, 10 (Aug. & Oct. 1967).

(13) Traffic Institute, Northwestern University; "Capacity Analysis Procedures for Signalized Intersections" Publication No. 3900.

(14) Ashby, H. S., R. C. Stahman, B. H. Eccleston, R. W. Hurn; "Vehicle Emissions-Summer to Winter"; Paper No. 741053 Presented at the Society of Automatic Engineers Automobile Engineering Meeting; Toronto, Canada; (October 21-25, 1974); Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pa. 15096.

(15) Williams, M. E., J. T. White, L. A. Platte and C. J. Domke; "Automobile Exhaust Emission Surveillance -- Analysis of the FY72 Program"; *EPA 460/2-74-001*; (February 1974); National Technical Information Service, Springfield, Va. 22161.

SUPPLEMENTAL REFERENCES

(1) Traffic Information Requirements for Estimates of Highway Impact on Air Quality, Air Quality Manual Vol. III, FHWA-RD-72-35. Prepared for Federal Highway Administration, Office of Research, Washington, D.C.

(2) Lynch, Kevin, 1962. Site Planning. The M.I.T. Press, Massachusetts Institute of Technology, Cambridge, Massachusette.

(3) Benioff, Barry and Ahmad Moghaddas. February 1970, "Stopped Vehicle Spacing on Freeways," Traffic Engineering.

(4) Automobile Exhaust Emission Surveillance. May 1973. Prepared for Environmental Protection Agency by Calspan Corporation. PB-220-755.

(5) U S. Department of Commerce, Bureau of Public Roads, Highway Statistics, GPO, Washington, D. C.

(6) May, D. A., "Traffic Characteristics and Phenomena on High Density Controlled Access Facilities." Traffic Engineering, 31: No. 6, 11-19, 56 (March 1961).

(7) Keefer, L. E., "The Relation Between Speed and Volume on Urban Streets," Quality of Urban Traffic Service Committee Report, HRB, 37th Ann. Meeting (1958) (unpubl.).

(8) Webb, G. M. and K. Moskowitz, "California Freeway Capacity Study--1956." Proc. HRB, 36: 587-642 (1957).

(9) Edit, L. C., R. S. Foote, R. Herman, and R. Rothery, "Analysis of Single-Lane Traffic Flow." Traffic Engineering, 33: No. 4, 21-27 (January 1963).

APPENDIX B. METHOD FOR ESTIMATING GROUND TRAFFIC EMISSIONS FROM AIRPORTS

This appendix is intended to provide guidance concerning a more detailed analysis of proposed indirect sources should this be necessary or desirable pursuant to 40 CFR 52.22(b). The materials contained herein are offered as suggestions. Alternate analytical approaches for evaluating the impact of a proposed source may be used if it can be demonstrated that they are more applicable to the source under review.

U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, N. C. 27711

January 1975

APPENDIX B.

METHOD FOR ESTIMATING GROUND TRAFFIC EMISSIONS FROM AIRPORTS

The purpose of this Appendix is to provide a means for estimating emissions from ground traffic at airports which handle primarily commercial carrier-type operations. It has been estimated[1] that within the next 10 years, 112 new airports of this nature are likely to built. Consequently, the development of major new airports to handle commercial carriers is a relatively rare event, and it is likely that a detailed environmental impact statement would be required to accompany the development of each such airport. Argonne National Laboratory, under contract to the Environmental Protection Agency, is preparing a methodology for assessing the many impacts arising from development of a new or larger airport. The air pollution impact is discussed in detail in APTD 1470.[1] The accompanying analysis is intended to provide suggestions for fulfilling the more limited goal of estimating emissions of pollutants from ground traffic which can ultimately be used to assess the impact of the airport on air quality. The methodology for estimating emissions from ground traffic at airports is summarized in Section BI. The remaining sections provide suggestions for implementing the methodology in Section BI.

BI. Summary of the Methodology for Estimating Emissions Associated with Airports

A. Macro-Analysis

1. Obtain the parameters indicated as essential from Table B1.

2. Use AP-42[2] to obtain emissions from relevant stationary sources.

3. Use Table B2 to estimate appropriate emission factors for light-duty vehicles in 1975. Use Equations (B3) - (B5) for emission factors for other years. Correct for cold starts-cold temperatures and altitude using guidance in Section 4.4 of the screening procedure or Supplement 5 to AP-42.[6]

4. Estimate traffic demands.

a. If trip data are available from the developer, use Equations (B7) - (B12).

b. If trip data are not available but population data are, use Equations (B13), (B13a), (B14), (B17) - (B19) to estimate ADT and then use Equations (B7) - (B12).

c. If neither trip nor population data are available, use aircraft operation data. Use Table B4, (B17) - (B22), (B13), (B13a) and (B14) to estimate ADT. Then use Equations (B7) - (B12) to estimate traffic demands of interest.

5. Estimate running times.

a. Running time within the airport. Use Equation (B24) to estimate a typical running time after using Equations (B24), (B25) and (B27) - (B31) (for non-signalized intersections) or (B32) (for signalized intersections) to determine running times for vehicles going through each entrance/exit gate and base running time. Estimate average running time with Equation (B33).

b. Impact of the airport on emissions within 3 miles of the airport.

Estimate typical vehicle speed and travel distance based on design information on planned and existing access roads and the distribution of volume demand over each road segment. Follow the procedure outlined in the macro-analysis section of Appendix A.

6. Estimate emissions using Equation (B1) plus emissions from stationary sources.

B. Micro-Analysis

Refer to the micro-analysis section in Appendix A to estimate the impact of freely flowing and/or queuing traffic on nearby CO concentrations. The procedure is as follows:

1. Estimate traffic demand for each lane j in road segment i using Equations (A12) or (A13). If necessary, adjust the demand for the impact of mass transit using Equations (A14) or (A15). Apportion demand among lanes, making sure that Equation (A2) is satisfied.

2. If the analysis does not concern an at-grade intersection, estimate capacity of the road segment using Equation (A10) and the lane capacities using Equation (A16). Check that Equation (A3) is satisfied. If not, adjust the lane capacities so that Equation (A3) is satisfied.

3. Determine volume to capacity ratios (v_{ij}/c_{ij}) for each lane. Given the type of road and the average highway speed, use the appropriate one of Figures A2-A5 to estimate vehicle operating speeds in each lane.

4. Use Figure A6 to estimate the speed corrected 1975 emission factor for each lane. For years other than 1975, adjust this factor with Equation (A17). Use guidance in Section 4.4 of the screening procedure or Supplement 5 to AP-42[6] to correct for cold starts and ambient temperatures, as needed.

5. Use Equation (A11) to estimate the line source emission intensity of freely flowing traffic.

6. For at-grade signalized intersections, use information concerning signal cycle lengths and green time to signal cycle ratios to estimate queue lengths with Equation (A18). Consider emissions to be the sum of those from freely flowing traffic and excess emissions occurring over the queue length. Estimate emissions from freely flowing traffic using Equation (A11), and excess emissions using Equation (A19). Alternatively, use the information in Tables A8-A12 directly to estimate appropriate emissions and queue lengths.

7. For non-signalized intersections, estimate the average queue length using Equation (A20). Use Equation (A21) to estimate the emission intensity over the queue at the intersection approach. Estimate the distance over which vehicles may accelerate and decelerate using Equation (A22). The emission intensity over this distance is obtained using Equation (A23). Use Equation (A11) to estimate emission intensity elsewhere.

BII. Key Operating and Design Variables

In a report prepared for EPA[3], one of three sets of airport utilization parameters is considered to be an essential prerequisite for estimating emissions from ground traffic associated with airport activities. The preferable set would be trip data. If these data are not available, then data concerning airport population or aircraft operations would have to serve as the starting point for deriving trip data and ultimately emission data. In any case, certain airport design information should be required from developers. This design information should include a schematic layout of the airport with approximate dimensions indicated, the number of public parking spaces available, number of parking lot gates, gate capacities, terminal curb frontage and frontage road capacity. Table BI summarizes needed parameters which should be supplied. Referring to Table B1, parameters in group ID as well as a complete set of group IA or B or C parameters are essential. It would be desirable to have the information specified in group II "useful" parameters for the individual airport planned. However, if this information is not available, estimates can be obtained from the data gathered for EPA for 13 major airports. If the planned airports would not cater primarily to commercial carrier operations, certain of the "useful parameters" in Table B1 would become essential since the approximations in this appendix are based on observations at airports servicing primarily commercial carrier operations.

A. Emissions from Stationary Sources

1. Macro-Analysis

For the "area-wide analysis" required in the Federal regulations[4] it is only necessary to estimate total emissions arising from airport related activities. In this type of analysis, one need not be overly concerned with the spatial distribution of emissions. Since CO, photochemical oxidants and NO_x are of most concern, emissions of CO, total hydrocarbons and NO_x are of prime interest. The only two types of stationary sources, associated with airports, which may be significant are combustion sources and refuse incinerators. Estimates should be made of the tons (coal or refuse), gallons (oil) or cubic feet (gas) of material likely to be consumed in a year. This estimate can be made using degree-day data and the anticipated size of facilities. Annual emissions of CO, HC and NO_x from these sources may then be estimated using the appropriate emission factors presented in tables in Chapters 1 and 2 of AP-42.[2] Since stationary source emissions associated with the airport are likely to be small compared with those from mobile sources, daily emissions from combustion sources could be estimated by dividing the annual amount of fuel consumed by days in the heating season. Daily refuse consumption would simply be the annual figure divided by days in the year. Similarly, unless better information is available, uniform emission rates throughout the day would probably suffice.

2. Micro-Analysis

A more detailed look at stationary sources of CO may be required in the micro-analysis for peak CO concentrations. Procedures for estimating maximum ground-level concentrations resulting from elevated point sources of emissions are presented in Volume 10 to the Guidelines for Air Quality Maintenance Planning and Analysis[5].

BIII. Emissions from Mobile Sources

A. Macro-Analysis

The major impact of the airport on air quality will arise from mobile sources. Equation (B1) is used to estimate the emissions from mobile sources.

Table B1. COMMERCIAL AIRPORT PARAMETERS NEEDED FOR AIR QUALITY IMPACT ANALYSIS

I. Essential Parameters

Parameters	Remarks
A. Trip Data	
--ADT	Average daily trip generation rate, where a "trip" is a one-way trip to or from the airport. A round trip would be 2 "trips."
B. Passenger/Employee/Visitor Parameters	
--Average Daily Airport Population	Includes passengers, visitors employees.
--Estimated Fraction of Passengers on Through Flights or Transferring Planes	This parameter could vary markedly depending on airport location.
-- Fraction of Passengers Accommodated by Mass Transit	
-- Number of Buses	
C. Aircraft Operations	
--Annual Number of LTO Cycles	One LTO cycle is one landing plus one takeoff.
--Estimated Passenger Seats per LTO Cycle	This depends on the mix of commercial aircraft classes.
--Number of Airport Employees	This parameter is needed because there is no clear-cut relationship between employees and aircraft operations discernible.

Table B1 (Continued)

D. Design Parameters	Remarks
--Number of Public Parking Spaces	
--Number of Gates	
--Gate Capacities	
--Gate Traffic Control Characteristics	For example, green time to signal cycle ratios and signal cycle lengths
--Number of Employee Parking Spaces	
--Terminal Curb Frontage	
--Terminal Frontage Road Capacity	
--Plans and/or Blueprints	To provide a schematic picture of access roads, traffic lanes, and the dimensions of the complex.

II. Useful Parameters

--Peak Daily Airport Population

--Peak and Average Daily Passenger Population

--Peak and Average Daily Visitor Population

--Vehicles/Airport Population

--Peak and Average Daily Employee Population

--Peak and Average Daily Vehicle Population

--Percent Peak 1-hr. and 8-hr. Vehicle Trips of Peak Daily Trips

--Percent Peak 1-hr. and 8-hr. Employee Trips of Peak Daily Trips

--Percent Peak 1-hr. and 8-hr. Passenger and Visitor Trips of Peak Daily Trips

--Percent Vehicle Trips from 6-9 A.M. of Peak Daily Vehicles Trips

--Peak Daily, Hourly and 8-hr. LTO's

--LTO's from 6-9 A.M. on Peak Day

--Typical Percent of Aircraft Seating Capacity Filled

Table B1 (Continued)

II. Useful Parameters (Continued)	Remarks
--Vehicles/LTO	
--Peak Daily Trip Rate	
--Peak Hourly Trip Rate	
--Peak 8-hr. Trip Rate	
--Peak Trip Rate (6-9 A.M.)	
--Peak Trip Rate (6 P.M.-6 A.M.)	
--Yearly Trip Rate	
--Base Running Time at Airport	Typical running time by a vehicle with no congestion.
--Average Speed on Airport Access Roads	Outside of the airport but within three miles of the boundary.

$$Q_M = \left[\frac{(EF)(V)(RT)}{216{,}000}\right]_{\text{Airport}} + \left(\frac{1}{3600}\right)\left[\sum_{K=1}^{M} (d_k)\ (ef)\ (C(S)_k)\ (V_k)\right] \qquad (B1)$$

Q_M = emissions from mobile sources gm/sec

EF = emission factor gm/veh-min

V = traffic demand, vph

RT = typical vehicle running time, sec

M = total number of road segments within area of interest

d_k = length of road segment k, mi

ef = emission factor for appropriate year and pollutant, gm/veh-mi (obtained from Table A3, Appendix A or if the assumptions in Table A3 are inappropriate, from Supplement 5 to AP-42[6])

$(C(S)_k)$ = speed correction factor (from Supplement 5 to AP-42[6])

(V_k) = traffic demand on road segment k resulting from airport traffic plus other traffic, vph

$\frac{1}{216{,}000}$ = conversion factor from $\frac{\text{gm-sec}}{\text{min-hr.}}$ to gm/sec.

$\frac{1}{3600}$ = conversion factor from hr^{-1} to sec^{-1}.

The first term in Equation (B1) estimates emissions within the bounds of the airport, while the second term covers emissions outside of the airport but within a 3-mile radius of the property line.

1. Calculation of Emission Factors (EF)

Since the designated area of interest with regard to estimating airport-related emissions is anywhere within 3 miles of the airport, a variety of emission factors may be needed to account for different operation speeds. For example, speeds near 0 mph may be assumed in the parking lots while somewhat higher speeds would be expected to occur on access roads. In Table B2, the emission factors were obtained using Table A3, speed correction factors derived from Tables 3.1.2-6a and 3.1.2-6b in Supplement 5 to AP-42[6] and Equation (B2).

$$EF = (cf)(ef)(Speed)/60 \qquad (B2)$$

where EF = emission factor, gm/min-veh

cf = the speed correction factor

ef = the emission factor in gm/mi-veh and

"Speed" = the assumed vehicle operating speed, mph.

If the projected mix of vehicles utilizing the airport has an important share of heavy-duty vehicles (e.g., buses), or is unusual in some other respect, Supplement 5 to AP-42[6] should be used to derive a more appropriate factor. The resulting value would be substituted for "EF" in Equation (B2) and for the "Table A3 value" in Equations (B3) - (B5). This procedure assumes the variation of heavy-duty emission factors with speed is similar to that for light-duty vehicles. The preceding discussion has assumed that 20% of the vehicles are operating from cold starts and that the area is relatively near sea level. Further the effect of ambient temperature (T) on emissions may introduce an additional correction factor. This is of particular importance for CO, and the discussion in Section 4.4 concerning CO correction factors should be referred to. The effect of ambient temperature on HC and NO_x emissions can probably be ignored. The data concerning NO_x emissions vs.

Table B2. AVERAGE EMISSION FACTORS FOR HIGHWAY VEHICLES*

Pollutant \ Speed (mph)	0	5	10	20	30	40	45
CO	20.0	19.5	19.0	18.0	17.2	16.5	16.4
HC's (exhaust + crankcase and evaporation)+	--	2.24	2.47	2.80	2.99	3.22	3.38
NO_x (as NO_2)	--	.36	.69	1.33	2.16	3.09	3.60

*Numbers are in gm/min-veh for a 1975 national average mix by model year of light-duty vehicles (88% cars, 12% light trucks).

+Non-exhaust HC emissions do not vary with vehicle speed.

If some year other than 1975 is of interest, emission factors for that year may be obtained as shown in Equations (B3) - (B5).

$$\text{For CO:}\quad EF = \left[\frac{\begin{pmatrix}\text{Table A3 Value}\\ \text{for Year of Interest}\end{pmatrix}}{55}\right]\begin{pmatrix}\text{Table B2 Value for}\\ \text{Speed of Interest}\end{pmatrix} \qquad \text{(B3)}$$

$$\text{For HC's:}\quad EF = \left[\frac{\begin{pmatrix}\text{Table A3 Value}\\ \text{for Year of Interest}\end{pmatrix}}{7.7}\right]\begin{pmatrix}\text{Table B2 Value for}\\ \text{Speed of Interest}\end{pmatrix} \qquad \text{(B4)}$$

$$\text{For } NO_x\text{:}\quad EF = \left[\frac{\begin{pmatrix}\text{Table A3 Value}\\ \text{for Year of Interest}\end{pmatrix}}{4.0}\right]\begin{pmatrix}\text{Table B2 Value for}\\ \text{Speed of Interest}\end{pmatrix} \qquad \text{(B5)}$$

ambient temperatures are ambiguous,[9] while HC (as a precursor of oxidants) is chiefly of interest at relatively high ambient temperatures. If ambient temperatures exceeding 100°F were common, it may be necessary to introduce a correction factor for HC emissions.[9] Supplement 5 to AP-42[6] contains a more complete discussion of how HC emissions vary with temperature. It should also be pointed out that if it is determined that extra emissions attributable to cold starts and cold temperatures only occur for a relatively short time (e.g., 4 minutes), higher emission factors should be used only until a typical vehicle becomes warm.

2. Calculation of Traffic Demand (V)

There are three basic approaches which can be taken to estimate ground traffic demand generated by the airport's presence.

a. Trip Data

First, and most preferable, one can work directly with expected trip generation rates provided by the developer. This type of information could take 2 forms. Ideally, the trip generation estimates would correspond to the periods of interest specified by applicable air quality standards. On the Federal level, this would mean:

(1) For carbon monoxide:
The peak hourly trip generation rate;
the peak 8-hour trip generation rate.

(2) For hydrocarbons and photochemical oxidants:
Peak trip generation rate from 6 A.M. to 9 A.M.;
peak daily trip generation rate.

(3) For NO_x:
Annual average daily trip generation rate.

Estimates of this sort may be difficult to obtain, however. Annual average daily trip generation estimates may be all that are possible. If this is the case, data compiled for EPA[3] for a sample of airports would be used to infer trip generation rates for appropriate periods. Equations (B7) - (B12) provide means for estimating trip generation rates for various periods of time. Equations (B7) - (B12) were derived using Tables 12 and 16 in reference 3, information about the relative numbers of passengers, visitors and employees on peak and average days and the assumption that employees and visitors' trips are two-way.

$$\text{Peak Daily Trip Rate, PDT} = .054\ \text{ADT} \tag{B7}$$

$$\text{Peak Hourly Trip Rate} = .079\ \text{PDT} = .112\ \text{ADT} \tag{B8}$$

$$\text{Peak 8-Hour Trip Rate} = .061\ \text{PDT} = .083\ \text{ADT} \tag{B9}$$

$$\underset{\text{(6-9 A.M.)}}{\text{Peak Trip Rate}} = .040\ \text{PDT} = .050\ \text{ADT} \tag{B10}$$

$$\underset{\text{(6 P.M. - 6 A.M.)}}{\text{Peak Trip Rate}} = .029\ \text{PDT} = .036\ \text{ADT} \tag{B11}$$

$$\text{Yearly Trip Rate} = .043\ \text{ADT} \tag{B12}$$

The appropriate units for the left-hand sides of Equations (B7) - (B12) are in vehicles per hour (vph). ADT in Equations (B7) - (B12) is the annual average daily trip rate, trips/day.

b. Airport Population Data

In some instances, a developer may only have airport population estimates rather than direct estimates about trip generation rates. Airport populations are divided into 3 distinct categories:

passengers, visitors and employees. Obviously, if there is specific information available about peak and typical numbers for each category, this should be used. Otherwise, the information in Table B3, which has been compiled from a sample of 13 major airports, will have to suffice for estimating peak and typical numbers of passengers, visitors and employees present.

Table B3. ESTIMATES OF PEAK AND TYPICAL NUMBERS OF PASSENGERS, VISITORS AND EMPLOYEES

	Fraction of a Typical Day's Airport Population		
	Passengers	Visitors	Employees
Typical Day	.45	.33	.22
Peak Day	.60	.52	.23

Estimation of traffic volume from population data proceeds as follows. First, the number of passengers, visitors and employees on peak and typical days are computed by multiplying a typical day's airport population by the appropriate factors in Table B3. The second step is to estimate the number of vehicles used by passengers, visitors and employees. For passengers, this number is greatly dependent on the fraction of passengers simply transferring planes on a through-flight. These passengers do not generate any ground traffic at all. This fraction varies greatly depending on the location of the airport. It is essential that the developer provide an estimate of the fraction of through or transferring passengers in order for the control agency to successfully relate airport population to vehicle population. Once the fraction of transferring and through passengers is known, Equation (B13) may be used to estimate the number of vehicles used by passengers and visitors.

$$(\text{Veh})_{pv} = .75\ (\text{total passengers per day})\ (1-T) \qquad \text{(B13)}$$

where $(\text{Veh})_{pv}$ is the number of vehicles used per day by passengers and visitors;

T is the fraction of through and transferring passengers;

The parameter $(\text{Veh})_{pv}$ can be adjusted to reflect increased use of mass transit by applying Equation (B13a).

$$(\text{Veh})_{pv} = .75\ [(\text{total passengers})\ (1-b)]\ (1-T) + B \qquad \text{(B13a)}$$

where b = fraction of passengers using mass transit

B = number of buses running during period of interest

$$(\text{Veh})_{E} = .82\ (\text{Number of Employees Present per Day}) \qquad \text{(B14)}$$

Next, average daily traffic (ADT) can be estimated from the information present in Table B3, Equations (B13) and (B14). In estimating ADT, it is necessary to apportion $(\text{Veh})_{pv}$ among passengers who park their own vehicles and those who are dropped off or picked up by visitors. From Table B3, the total number of passengers originating or terminating their flights at the airport on an average day is:

$$P = .45\ (\text{Total Ave. Pop.})\ (1-T) \qquad \text{(B15)}$$

total number of visitors is:

$$V = .33\ (\text{Total Ave. Pop.}) \qquad \text{(B16)}$$

Thus, the fraction of vehicles driven by visitors of the total number of vehicles driven by passengers and visitors is:

$$F_v = \frac{.33}{.33 + .45\ (1-T)} \qquad \text{(B17)}$$

and the fraction driven by passengers is:

$$F_p = \frac{.45\ (1-T)}{.33 + .45\ (1-T)} \qquad \text{(B18)}$$

If the assumption is made that vehicles driven by visitors and employees make 2 trips per day (one coming, one going) and vehicles driven by passengers make 1 trip/day, then the average daily traffic is given by Equation (B19).

$$ADT = 2F_v(Veh)_{pv} + F_p(Veh)_{pv} + 2(Veh)_E \tag{B19}$$

The results of Equation (B19) can now be used in Equations (B7) - (B12) to estimate traffic volumes for appropriate periods of interest.

c. Aircraft Operation Data

The third and least preferable approach for estimating traffic volume is to use aircraft operation data to estimate ground traffic demand generated by passengers and visitors together with employee data. As with the other two approaches, if the developer is able to provide reliable estimates of the various "useful parameters" in Table B1, these should be used directly rather than derived using information based on EPA's limited sample of airports. Starting with the annual number of LTO cycles (1 Landing + 1 Takeoff Operation), the average daily number of LTO cycles would simply be:

$$\text{Daily LTO Cycles} = \frac{\text{Annual LTO Cycles}}{365} \tag{B20}$$

The other required parameter, passenger seats per LTO cycle, can be estimated by anticipating the "mix" of aircraft likely to be using the airport. Table B4 presents different classes of aircraft and the mean of mixes observed at 4 large airports^3.

Table B4. AIRCRAFT CLASSES AND THEIR OBSERVED UTILIZATION AT FOUR LARGE AIRPORTS

	Aircraft	Seating Capacity	% of LTO's at Airport (1969)
1.	SST	136	———
2.	Jumbo Jet	490	———
3.	Long-Range Jet	129	38%
4.	Medium-Range Jet	116	49%
5.	Turbo-Prop	61	13%
6.	Business Jet	10	———
7.	Piston Engine Utility	1	———

In the absence of more specific data from the developer, Table B4 is used to estimate a typical number of passenger seats per aircraft of about 115. This is equivalent to 230 passenger seats per LTO cycle. To estimate the number of passengers per LTO cycle, data provided by the developer on fraction of seating capacity utilization would be useful. If this information is unavailable, information compiled for EPA[3] indicates that in 1970 approximately 47% of seats were filled. Hence, one should use Equation (B21) or (B22) to estimate the number of passengers per LTO cycle.

$$P/LTO_{cycle} = \begin{pmatrix}\text{Passenger}\\ \text{Seats Per}\\ \text{LTO Cycle}\end{pmatrix} \begin{pmatrix}\text{Fraction of}\\ \text{Seating}\\ \text{Utilized}\end{pmatrix} \qquad \text{(B21)}$$

where P/LTO_{cycle} is the number of passengers per LTO cycle. Using data compiled for EPA[3], Equation (B21) becomes

$$P/LTO = (230)(.47) = 108 \qquad \text{(B22)}$$

Combining the results of Equations (B13), (B14), (B17), (B18), (B19) and (B20), one gets:

$$\begin{aligned} ADT = {} & .75 \text{ (Daily LTO Cycles) (P/LTO Cycles) } (1-T)[F_p + 2F_v] \\ & + 1.64 \text{ (Number of Employees)} \end{aligned} \qquad \text{(B23)}$$

Once the average daily traffic volume is obtained from Equation (B23), Equations (B7) - (B12) can be used to estimate traffic demand for the appropriate period of interest.

3. Calculation of Running Time(RT)

Total running time is the sum of running time associated with two types of traffic. The first is the amount of time a vehicle's engine runs within the boundaries of the airport. The second is the amount of time it takes a vehicle to reach a distance of greater than 3 miles (the distance cited in the Federal regulations[4] from the airport bounds).

Running time within the airport bounds is the sum of the "base running time" plus any additional time required to enter or leave a parking lot caused by congestion.

$$RT = \frac{BRT}{2} + \overline{RT}_q \qquad \text{(B24)}$$

Referring to Equation (B24), "BRT" is the base running time required for a vehicle to arrive, enter, move to a parking space, park, unpark, move to an exit lane, exit and depart from an airport parking lot. The base running time can be estimated by studying the physical configuration of the proposed airport and its parking lots. An example of the procedure which might be followed in estimating base running time from the airport's physical configuration and applicable traffic regulations is illustrated in Equations (B25a) - (B25h).

$$\text{Base Approach Time} = \left(\frac{\begin{array}{c}\text{Distance between entrance and nearest} \\ \text{intersection on the access road, m}\end{array}}{\text{(posted special limit, m/sec)}} \right) \qquad \text{(B25a)}$$

$$\text{Base Entrance Time} = \frac{\text{(Number of entrance lanes at main gate)}}{\text{(Main entrance gate capacity, veh/sec)}} \qquad \text{(B25b)}$$

$$\text{Base Movement in Time} = \frac{1.5 \text{ (Dist. from center of lot to main ent.), m}}{\text{(speed limit in lot, m/sec)}} \qquad \text{(B25c)}$$

$$\text{Base Parking Time} = 5\text{-}10 \text{ sec} \qquad \text{(B25d)}$$

$$\text{Base Unparking Time} = 5\text{-}10 \text{ sec} \qquad \text{(B25e)}$$

$$\text{Base Movement Out Time} = \frac{1.5\ \text{(Dist. from cen. of lot to main exit,m)}}{\text{(speed limit in lot)}} \qquad \text{(B25f)}$$

$$\text{Base Exit Time} = \frac{\text{(Number of exit lanes at main gate)}}{\text{(Main exit gate capacity, veh/sec)}} \qquad \text{(B25g)}$$

$$\text{Base Departure Time} = \frac{\left(\begin{array}{l}\text{Distance between main exit and nearest}\\ \text{intersection on access road, m}\end{array}\right)}{\text{(posted speed limit, m/sec)}} \qquad \text{(B25h)}$$

$$\begin{aligned} \text{BRT} = {} & \text{(B25a)} + \text{(B25b)} + \text{(B25c)} + \text{(B25d)} + \text{(B25e)} \\ & + \text{(B25f)} + \text{(B25g)} + \text{(B25h)} \end{aligned} \qquad \text{(B26)}$$

The "$\overline{RT_q}$" in Equation (B24) is the mean extra running time spent in exit or entrance queues. For each non-signalized exit/entrance gate, i, running time spent in a queue is estimated using an Equation from queuing theory[10].

$$(RT_q)_i = \frac{3600}{c_i}\left(\frac{v_i}{c_i - v_i}\right)^{*}, \quad v_i/c_i \leq .95 \qquad \text{(B27)}$$

$(RT_q)_i$ = running time spent in queue at gate i, sec

v_i = entering or exiting traffic volume demand at gate i, veh/hr.

c_i = gate capacity for gate i, veh/hr.

Use of Equation (B27) requires an estimate of how the total traffic volume demand during the time period of interest is apportioned among gates. If this estimate is unavailable from developers, Equations

---

*A separate analysis is needed for entering and exiting traffic.

(B28) or (B29) should be used to estimate the traffic volume demand at gate i.

$$v_i = V \left[\frac{\text{Capacity of access road i}}{\Sigma\ (\text{Capacity of all access roads})}\right] \tag{B28}$$

Or, if there are 2 or more gates exiting onto the same access road (or if access road capacity is unknown),

$$v_i = V \frac{c_i}{\sum\limits_{\text{all } i} c_i} \tag{B29}$$

It should be noted from Equation (B30) that as v_i approaches c_i, $(RT_q)_i$ becomes very large. The following suggestions are therefore made.

$$(RT_q)_i = 3600(20/c_i),\ .95 < v_i/c_i \leq 1 \tag{B30}$$

$$(RT_q)_i = 3600 \left[20/c_i + \frac{(v_i - c_i)}{2c_i} \right],\ v_i/c_i > 1 \tag{B31}$$

Equation (B31) assumes the length of the line at exit/entrance is small at the beginning of the time period of interest. If this assumption were not valid, Equation (B31) should be altered as shown in Equation (B31a).

$$(RT_q)_i = 20/c_i + \frac{\text{(average queue length)}}{c_i} \quad i,\ v_i/c_i > 1 \qquad \text{(B31a)}$$

Excess running time spent entering or exiting from a parking lot with signalized exit/entrances may be estimated using Equation (B32).

$$(RT_q)_i = \left[\frac{(C_y)(c')(1-G/C_y)^2}{2(c'-v)} + \frac{1800\ vC_y{}^2}{c'G(c'G-vC_y)} \right]_i \qquad \text{(B32)}$$

where

$(RT_q)_i$ = excess running time spent exiting or entering at exit/entrance i, sec

C_y = signal cycle length, sec

c' = unimpeded capacity at a signalized intersection approach, vph

G = amount of green time per signal cycle for the intersection approach of interest, sec

G/C_y = green time to signal cycle ratio, dimensionless

v = traffic demand at the intersection approach of interest, vph.

Equation (B32) is adapted from concepts expressed by Newell[11] concerning times spent by vehicles at approaches to signalized intersections. The average running time spent in queues in Equation (B24) is simply

$$\overline{RT}_q = \frac{\sum\limits_{\text{all}_i} (RT_q)_i}{I} \qquad \text{(B33)}$$

where I = the total number of exit and entrance gates.

B. Micro-Analysis

If it is of interest to estimate peak CO concentrations in the vicinity of exits/entrances to parking lots, in the vicinity of access roads or at nearby intersection approaches, it is essential that emission estimates from traffic in traffic lanes located near by the receptor of interest be estimated. Two situations are of general interest: the case where traffic flows freely by the receptor; and the case where queues form in the vicinity of the receptor. At traffic lanes within or adjacent to the airport parking lot, the impact of freely flowing and/or queuing vehicles on CO concentrations in the vicinity of the lanes should be added to CO concentration estimates obtained using an area source model relating the source's size and emission density to CO concentrations, and general background levels. More details concerning this procedure are presented in Appendix H. The first term in Equation (B1) may be divided by the area of the parking lot to obtain an estimate of emission density, as shown in Equation (B34).

$$Q = \frac{(EF)(V)(RT)}{216{,}000\ A} \qquad \text{(B34)}$$

where Q = emission density, gm/sec-m^2

A = parking lot area, m^2

All other terms are as defined for Equation (B1).

The discussion in Appendix A concerning microscale impact analysis may be used to estimate the impact of freely flowing or queuing traffic on nearby CO concentrations. Equation (A11) is used to estimate emissions from freely flowing traffic. If traffic in the vicinity of a signalized intersection is of interest, excess emissions over a finite queue (obtained using Equations (A18) and (A19)) are added to emissions estimated for an infinite line source of freely flowing traffic with Equation (A11). Emissions at a non-signalized intersection may be approximated with Equations (A20) - (A23) and with Equation (A11).

C. Emissions Outside the Airport but within a Three-Mile Radius of the Airport Boundary

Since there is a need to estimate the aggregate impact of airport-related emissions in the vicinity of the airport, a methodology is suggested for doing so. Emissions covered by the methodology relate only to those generated by vehicular traffic going to and from the airport. Other emissions, such as those generated by stationary sources like motels and service industries, are not considered in this treatment. Specific treatment of the impact of such facilities or of traffic related to them which is not directly dependent on the airport is not possible without considering the specific area. This limitation arises as the result of the dependence of subsequent development on existing land use patterns in the airport's vicinity, future land use plans and the availability of appropriate services located elsewhere.

In estimating vehicular emissions outside the airport boundaries, the traffic volume assumed should be the same as that estimated within the airport for the period of interest. This traffic volume should then be apportioned among roads comprising the road network within 3 miles of the airport. Traffic volume not related to the airport but using network should be estimated using the methodology described in the macro-analysis section of Appendix A. The traffic volume to and from the airport during periods of interest should be superimposed upon these estimates to obtain total traffic volume demand on each road segment, (V_k). The resulting volume demand should then be used, in conjunction with the segment's capacity (C_k) to estimate average operating speeds and speed adjusted emission factors for each road segment, as described in Appendix A. The resulting emissions obtained from Equation (B1) should be compared with those which would result without the presence of the airport in order to assess the net impact of the airport on CO, HC and NO_x emissions.

REFERENCES

(1) Norco, J.E., P.R. Cirillo, T.E. Baldwin and J.W. Gudenas; "An Air Pollution Impact Methodology for Airports and Attendant Land Use--Phase I"; APTD 1470 (January 1973).

(2) Compilation of Air Pollutant Emission Factors, EPA Publication No. AP-42 (Second Edition), (April 1973).

(3) Thayer, S.D.; "Vehicle Behavior in and Around Complex Sources and Related Complex Source Characteristics: Volume I--Airports"; EPA-450/3-74-003-b;(August 1973); National Technical Information Service, Springfield, Virginia 22161.

(4) 40CFR52; "Approval and Promulgation of Implementation Plans: Review of Indirect Sources"; Federal Register; (July 9, 1974); P.25292.

(5) U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards; "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 10: Reviewing New Stationary Sources"; EPA-450/4-74-011; (September 1974); Air Pollution Technical Information Center, Research Triangle Park, N.C. 27711.

(6) U.S. EPA; "Compilation of Air Pollutant Emission Factors"; Publication Number AP-42; Supplement 5 to the Second Edition; (In Press 1975); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(7) Williams, M.E., J.T. White, L.A. Platte and C.J. Domke; "Automobile Exhaust Emission Surveillance--Analysis of the FY 72 Program"; EPA-460/2-74-001; (February 1974); National Technical Information Service; Springfield, Virginia 22161.

(8) 40CFR85: "1975 Federal Test Procedure"; Federal Register 36 No. 128; (July 2, 1971).

(9) Ashby, H.A., R.C. Stahman, B.H. Eccleston, R.W. Hurn; "Vehicle Emissions--Summer to Winter"; Paper No. 741053, presented at the Society of Automotive Engineers Automobile Engineering Meeting, Toronto, Canada (October 21-25, 1974); Society of Automotive Engineers, Inc.; 400 Commonwealth Drive, Warrendale, Pa. 15096.

(10) Hillier, F.S. and G.J. Lieberman; Introduction to Operations Research; Holden-Day, Inc.; (1967); Ch. 10.

(11) Newell, G.F.; "Approximate Methods for Queues with Application to the Fixed Cycle Traffic Light"; S. I. A. M. Review; 7 No. 2;(1965).

APPENDIX C. METHODS FOR ESTIMATING EMISSIONS IN VICINITY OF REGIONAL SHOPPING CENTERS

This appendix is intended to provide guidance concerning a more detailed analysis of proposed indirect sources should this be necessary or desirable pursuant to 40 CFR 52.22(b). The materials contained herein are offered as suggestions. Alternate analytical approaches for evaluating the impact of a proposed source may be used if it can be demonstrated that they are more applicable to the source under review.

U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

January 1975

APPENDIX C.

METHODS FOR ESTIMATING EMISSIONS IN VICINITY OF REGIONAL SHOPPING CENTERS

The purpose of this Appendix is to provide a means for assisting air pollution control agencies, applicants and consultants to estimate CO emissions in the immediate vicinity of a regional shopping center. A regional shopping center is thought of as one having more than 300,000 square feet of gross leasible floor space and characterized by at least one or two major department stores. The major difference between regional and community or neighborhood shopping centers, other than size, is tenant mix. Generally, the tenant mix at the smaller shopping centers results in shorter visits and, therefore, smaller accumulations of vehicles within the parking lots. If it is possible to obtain an estimate of average daily trip generation rates and diurnal and seasonal usage patterns for a proposed community or neighborhood shopping center, the methodology described in Appendix C could be applied to these smaller centers as well. If it is necessary to estimate HC and NO_x emissions at the shopping center, emission factors should be obtained for these pollutants as described in Appendix B.

If such a macro-analysis is performed, it is essential that any reduction in vehicle miles traveled, arising from the use of the large regional center at the expense of a number of smaller centers, be accounted for. This consideration is particularly crucial for shopping centers, which are among the most competitive of the indirect sources considered in the Federal Regulations.

Section CI of this Appendix summarizes one means which could be used to estimate total CO emissions arising from the operation of a regional shopping center. A methodology for estimating CO emissions in the vicinity of locations likely to experience peak CO concentrations (e.g. exit/entrance gates, traffic lanes at nearby intersections) is also presented. The remaining portions of the Appendix discuss how the procedures described in Section CI might best be implemented.

CI. Procedure for Estimating Emissions in the Vicinity of Regional Shopping Centers

1. Obtain design and operating parameters indicated as essential in Table C1. If possible obtain estimates for the other parameters which are indicated as important in Table C1.

2. Estimate appropriate emission factors using modal emission model applicable for shopping centers. If this is not possible, use Figure C1 and, if necessary, Equation (C4). Correct for cold start-cold temperature emissions using Section 4.4 in the screening procedure or Supplement 5 to AP-42. If the vehicle mix is substantially different from that assumed in deriving Figure C1, review Supplement 5 to AP-42[3] and derive appropriate average trip emission factors.

3. Estimate volume demand at the shopping center using (a) the developer's estimates; or (b) Eqs. (C5a) and (C5b); or (c) Eqs. (C6a), (C6b), (C6c) and (C6d).

4. If it is necessary, adjust traffic volume demand to consider increased use of mass transit, using Eqs. (C6e) and (C6f).

5. Estimate Base Running Time using expressions similar to (C7a) - (C7g).

6. (a) If the lot is unsupervised and the accumulation of vehicles in the parking lot exceeds 80 percent of the parking capacity, use Table C3 to estimate a correction factor depicting the increase in running time attributable to the difficulty in finding and maneuvering into a parking space.

(b) If the lot is supervised, use an expression similar to (C8) to estimate the increase in running time when the lot is completely utilized.

7. Use Eqs. (C10) and (C11) or (C12) and (C13) to estimate entering and exiting traffic demands at each entering and exit gate.

8. Use Eqs. (C9) or (C14) or (C15) to estimate running time spent in queues at each exit and entrance gate not having a traffic signal. For signalized exits or entrances use Eq. (C16) to estimate delays spent in exit or entrance queues. Then use Eq. (C17) to estimate average running time spent in queues for all entrance and exit gates.

9. Use Eq. (C18) to estimate running time associated with a typical one-way trip at an unsupervised parking lot. If the lot is supervised, use Eq. (C19) instead.

10. Use Eq. (C1) to estimate total emissions at and in the vicinity of the shopping center which are attributable to the shopping center. Use Eq. (C2) to estimate emission density at the shopping center.

11. If point sources of CO are significant, use guidance in Volume 10 of "Guidelines for Air Quality Maintenance Planning and Analysis" discussing stationary sources. Add these emissions to those estimated for mobile sources.

12. Refer to the micro-analysis section in Appendix A to estimate the impact of freely flowing and/or queuing traffic on nearby CO concentrations. The procedure is as follows:

a. Estimate traffic demand for each lane j in road segment i using Eqs. (A12) or (A13). If necessary, adjust the demand for the impact of mass transit using Eqs. (A14) or (A15). Apportion demand among lanes, making sure that Eq. (A2) is satisfied.

b. If the analysis does not concern an at-grade intersection, estimate capacity of road segment using Eq. (A10) and the lane capacities using Eq. (A16). Check that Eq. (A3) is satisfied. If not, adjust the lane capacities so that Eq. (A3) is satisfied.

c. Determine volume to capacity ratios (v_{ij}/c_{ij}) for each lane. Given the type of road and the average highway speed, use the appropriate one of Figs. A2 - A5 to estimate vehicle operating speeds in each lane.

d. Use Fig. A6 to estimate the speed corrected 1975 emission factor for each lane. For years other than 1975, adjust this factor with Equation (A17). Use Section 4.4 of the screening procedure or Supplement 5 to AP-42 to correct for cold starts and ambient temperatures, as needed.

e. Use Eq. (A11) to estimate the line source emission intensity of freely flowing traffic.

f. For at-grade signalized intersections, use information concerning signal cycle lengths and green time to signal cycle ratios to estimate queue lengths with Eq. (A18). Consider emissions over the queue length to be the sum of those from freely flowing traffic and excess emissions. Elsewhere, emissions are attributable to freely flowing traffic. Estimate emissions from freely flowing traffic using Eq. (A11), and excess emissions using Eq. (A19). Alternatively, use the information in Tables A8-A12 directly to estimate appropriate emissions and queue lengths.

g. For nonsignalized intersections, estimate the average queue length using Eq. (A20). Use Eq. (A21) to estimate the emission intensity over the queue at the intersection approach. Estimate the distance over which vehicles may accelerate and decelerate using Eq. (A22). The emission intensity over this distance is obtained using Eq. (A23). Use Eq. (A11) to estimate emission intensity elsewhere.

CII. Identification of Key Design and Operating Variables

Table C1 identifies key design and operating parameters which should be supplied by developers of shopping centers. Also listed in Table C1 are a number of optional parameters which should be obtained if possible.

Physical configuration of the shopping center provides an indication of size, arrangement of vehicles within the center and a means for estimating the amount of running time required for a vehicle to enter the parking lot, move to a parking space, park, unpark, move to an exit and exit. Number and capacity of exit/entrance gates are crucial parameters since highest CO concentrations are likely to occur in the vicinity of the gates. If the volume demand at a gate begins to approach the gate's capacity, extensive queuing is likely. The result is likely to be a large increase in vehicle running times leading in turn, to greater emissions. Configuration and lane capacities of access roads are important, because they may influence the demand at exit/entrance gates and provide a determinant of gate capacity. In addition, access road capacity, and the approach capacity at nearby intersections on access roads are prime considerations in determining whether CO levels will be high at the intersection as the result of extra traffic generated by the shopping center. Gross leasible floor space and tenant mix provide an indication of average trip duration and the number of parking spaces needed to accommodate demand and avoid congestion. Average daily trip generation rate, demand on access roads, peak demands, seasonal and diurnal demand patterns and distribution of traffic among gates determine the volume of traffic utilizing the source and passing key locations during any time of interest. When this information is combined with capacity information, the amount of congestion can be estimated by volume demand-capacity ratios. Average vehicle occupancy and mass transit usage are important in relating number of customers to number of vehicles at the center.

Table C1. KEY DESIGN AND OPERATING PARAMETERS FOR REGIONAL SHOPPING CENTERS

I. Essential Parameters

Parameters	Remarks
A. Design Parameters	
Plans or Blueprints of the Shopping Center and Surroundings	Should include such features as traffic lane locations, number of lanes at gates, design of gate approaches and design intersection approaches on access roads.
Number and Capacity of Exit/ Entrance Gates	
Access Road Configurations and Capacities (by lane preferably)	
Nearby Intersection Approach Capacities	
Gross Leasible Floor Space and Tenant Mix	
B. Operating Parameters	
Seasonal and Diurnal Trip Generation Rate Patterns and Use Patterns on Access Roads	
Angle of Parking	Affects time needed to park and unpark vehicle.
Average Daily Trip Generation Rate	Number of one-way trips per day. A trip to and from a shopping center represents two trips by this definition and thus counts each vehicle twice.
Traffic Volume Demand on Access Roads	Demand is the sum of traffic which is independent of the shopping center and shopping center traffic which has been properly apportioned among the roads on the surrounding road net.
Average Visitor Vehicle Occupancy	

Table C1. KEY DESIGN AND OPERATING PARAMETERS FOR REGIONAL SHOPPING CENTERS (Cont'd)

Parameters	Remarks
I. Essential Parameters	
Fraction of Visitors Using Mass Transit	
Number of Buses Arriving and Departing from the Center During Peak Daily 1- and 8-Hour Use Periods	
Green Time to Signal Cycle Ratio to Each Approach at Nearby Intersections	Needed to estimate approach capacities and queue lengths at approaches during the red phase of a signal.
Number of Traffic Signal Cycles per Hour at Each Intersection	Needed to estimate queue lengths at intersection approaches during the red phase of a signal.
II. Additional Useful Parameters	
A. Design Parameters	
Number of Available Parking Spaces to Visitors	
B. Operating Parameters	
Peak 1-Hour and 8-Hour Trip Generation Rates	
Highest 1-and 8-Hour Trip Generation Rates Occurring During Periods when Non-shopping Center Traffic is Greatest	
Distribution of Traffic Among Gates	Includes information about numbers of left- and right-hand turns.
Distribution of Operation Modes (i.e., acceleration, deceleration, etc.) for a Typical Vehicle Visiting a Shopping Center	Useful in obtaining good estimates for emission factors.

CIII. Estimating Emissions in the Vicinity of a Regional Shopping Center

Two types of analyses are desirable in estimating emissions in the vicinity of a regional shopping center: (1) Total emission rate attributable to vehicles and stationary sources should be estimated; (2) emissions in the vicinity of the most congested exits/entrances, and emissions in the vicinity of nearby intersections should be estimated.

A. Total Emission Rate. Total emission rate is of importance for two reasons:

(1) To provide a means (together with possible reduction of visits to competing shopping centers or stores) for relating the construction of the shopping center with emission density limitations which may be imposed by land use or air quality maintenance plans, and

(2) To provide a means for estimating the emission density at the shopping center and its resulting impact on background (or representative) concentrations of CO.

Volume 10 of the "Guidelines for Air Quality Maintenance Planning and Analysis"[1] should be consulted if stationary sources of CO will be significant at the proposed shopping center. Equation (C1) may be used to estimate total emission rate from vehicles visiting a shopping center.

$$Q_{tot} = \frac{(EF)(V)(RT)}{216,000} \qquad (C1)$$

If Q_{tot} is divided by the area of the shopping center and its surrounding parking lot, the center's emission density may be estimated.

$$Q = \frac{(EF)(V)(RT)}{216,000A} \qquad (C2)$$

where

Q = emission density, gm/sec-m^2

Q_{tot} = total emission rate, gm/sec

EF = emission factor, gm/min-veh

V = Traffic volume demand, veh/hr

RT = Typical vehicle running time for 1 trip during the period interest, sec

A = Area occupied by the shopping center and its parking lot, m^2

"1/216,000" is a conversion factor from $\frac{\text{gm-sec}}{\text{min-hr}}$ to gm/sec.

1. Estimating Emission Factors (EF)

Probably the most accurate estimates of CO emission factors at shopping centers could be obtained if typical driving cycles (i.e., amounts of time and sequence of acceleration, deceleration, steady speed modes of travel) were known for shopping centers. A typical driving cycle could then be simulated using the EPA Automobile Exhaust Emission Modal Analysis Model[2] to obtain average trip emission factors for shopping centers. This approach has been followed in characterizing emissions at signalized intersections in Appendix A. Unfortunately, there is not yet sufficient data available to use this technique elsewhere within a shopping center. In the meantime, use of the average trip emission factors contained in Supplement 5 to AP-42[3] may have to suffice. Figure C1 was obtained using the 1975 Federal Test Procedure emission factor for CO presented in Table A3 in Appendix A for a 1975 mix of light-duty vehicles (88% cars, 12% light trucks) at sea level and Tables 3.1.2-6a and b in Supplement 5, AP-42[3] to obtain appropriate speed correction factors (C(S)). Note that the emission factor at 0 mph represents a factor for stopping-and-starting traffic, rather than idling.

If the mix of vehicles at the shopping center were not predominantly composed of light-duty vehicles and/or the national average mix of model years assumed in deriving Figure C1 were not appropriate, Figure C1 could not be used and it would be necessary to refer to Supplement 5 to AP-42[3] to derive emission factors for the appropriate mix of vehicles utilizing the shopping center. The curve in Figure C1 is also based on the assumption that 20 percent of the vehicles are operating from cold starts under ambient temperatures ranging from 68°F-86°F at a location near sea level. If the assumptions concerning percentage of cold starts and ambient temperature used in deriving an emission factor are not appropriate, correction factors can be obtained using Equation (3.1.2-2) and Tables 3.1.2-7 or 3.1.2-8 in Supplement 5 to AP-42.[3] This procedure was followed in deriving the correction factors for CO emissions appearing in Section 4.4.1 of the screening procedure.

It should be pointed out that if it is determined that extra emissions attributable to cold starts and cold temperatures only occur for a relatively short time (e.g., 4 minutes), higher emission factors should be used only until a typical vehicle becomes warm.

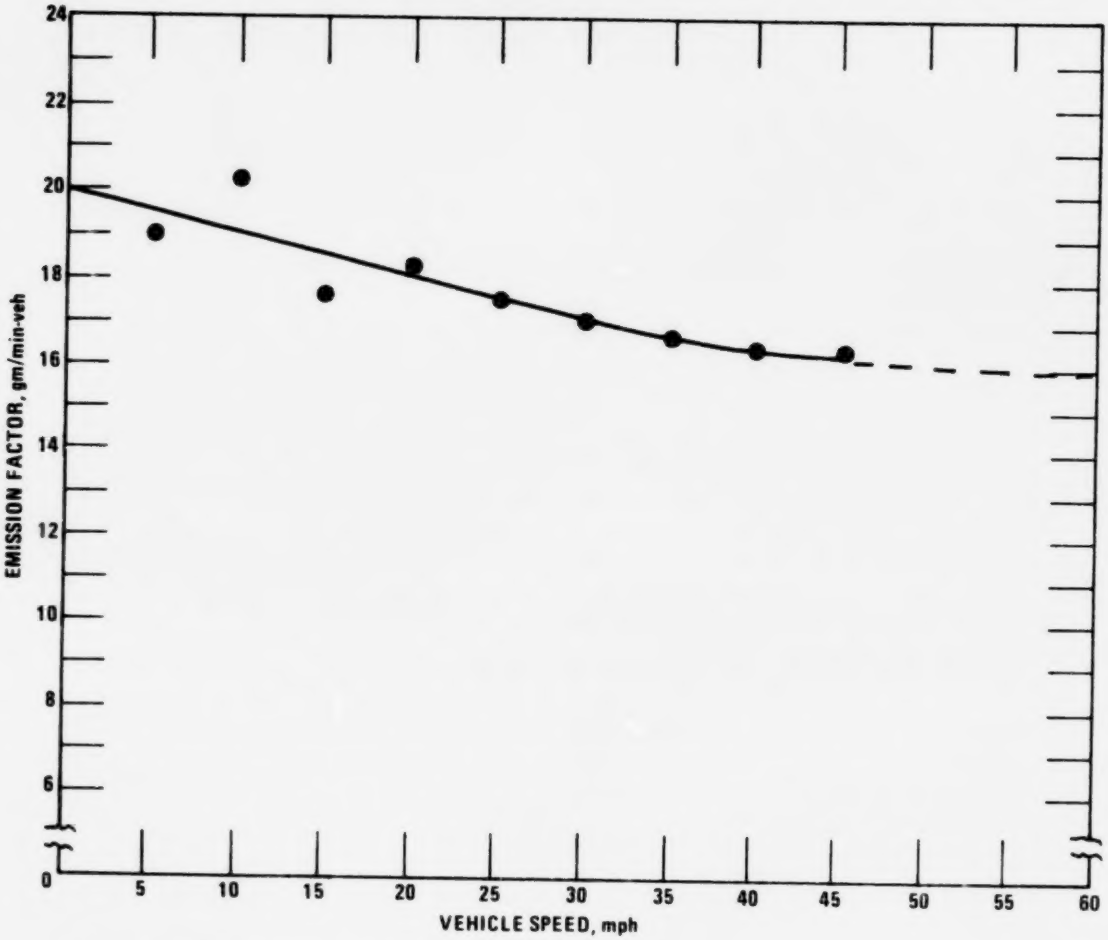


Figure C1. Composite emission factors for carbon monoxide for calendar year 1975.

Equation (C4) should be used to estimate CO emission factors for vehicle mixes during years other than 1975.

$$EF = \begin{bmatrix}\text{Calculated 1975} \\ \text{Emission Factor}\end{bmatrix} \left(\frac{ef}{55}\right) \qquad (C4)$$

where

ef = CO emission factor obtained from Table A3 in Appendix A3 for the year of interest, gm/mi-veh

"55" = CO emission factor for 1975 obtained from Table A3, gm/mi-veh

2. Estimation of Traffic Volume Demand (V)

There are three ways in which this parameter may be estimated. These are listed in descending order of preference.

a. Use peak 1-hour and 8-hour trip generation rates (vehicles per hour) provided by the developer as the result of a bonafide study of the locale. Alternatively, if traffic on the surrounding road net is the prime consideration, periods in which the sum of shopping center traffic and other traffic is greatest would be of most interest. In locations where there is substantial traffic not related to the shopping center, the highest demand on the surrounding roads (attributable in part to the shopping center) may not occur when demand generated by the shopping center is greatest. It has been suggested that for such cases peak hourly traffic demands appropriate for 1- and 8-hour periods on the day having the tenth highest daily demand be used.[7] Such a procedure would avoid holidays and Saturdays in December when unrelated traffic may be light.

b. Use expected average daily trip generation rate provided by developer together with seasonal and diurnal usage patterns applicable for similar existing shopping centers in the area to estimate peak 1- and 8-hour traffic volume demand. This procedure is illustrated in Equations (C5a) and (C5b).

(1) For 1-hour:

$$V = (\text{ADT})\left(\begin{array}{l}\text{Peak Seasonal Demand}\\ \text{Adjustment Factor}\end{array}\right)\left(\frac{\begin{array}{l}\text{Peak Hour Demand at Existing}\\ \text{Nearby Similar Facilities}\end{array}}{\begin{array}{l}\text{Peak Seasonal Daily Demand @}\\ \text{Existing Nearby Similar Facilities}\end{array}}\right) \quad \text{(C5a)}$$

where

ADT = Average daily trip generation rate, vehicles/day

V = Traffic volume demand, vph

(2) For 8 hours:

$$V = \frac{(\text{ADT})\left(\begin{array}{l}\text{Peak Seasonal Demand}\\ \text{Adjustment Factor}\end{array}\right)\left(\frac{\begin{array}{l}\text{Peak 8-hr. Demand at Existing}\\ \text{Nearby Similar Facilities}\end{array}}{\begin{array}{l}\text{Peak Seasonal Daily Demand at}\\ \text{Existing Nearby Similar Facilities}\end{array}}\right)}{8} \quad \text{(C5b)}$$

3. If data from nearby existing facilities are unavailable, estimate peak 1-hour and 8-hour traffic volume demand from data compiled for EPA from a limited sample of regional shopping centers.[8]

a. Weekday Peak Hour Volume: $V = .16\ \text{ADT}$ (C6a)

This is assumed to occur from 8-9 p.m. within 12 shopping days of Christmas.[8]

b. Weekday Peak 8-hour Volume: $V = .12\ \text{ADT}$ (C6b)

This is assumed to occur from 1-9 p.m. within 12 shopping days of Christmas.[8]

c. Saturday Peak Hour Volume: $V = .24\ ADT$ (C6c)

This is assumed to occur from 3-4 p.m. the Saturday before Christmas.[8]

d. Saturday Peak 8-hour Volume: $V = .16\ ADT$ (C6d)

This is assumed to occur from 10 a.m. to 6 p.m. the Saturday before Christmas.[8] "V" in Equations (C6a) - (C6d) is in vph.

Table C2 is presented to provide an indication of ranges of Average Daily Trip Generation Rates likely to be estimated for various sizes of regional shopping centers.

If it were of interest to note the impact of increasing the use of mass transit at the shopping center above the usage already inherently included in the developer's estimate of Average Daily Trip Generation Rates, it would be necessary to adjust the estimated volume demand. The adjusted volume demand could be estimated as shown in Eq. (C6e) for one hour periods.

$$V' = V - \frac{(T)(P)}{(avo)} + B \qquad \text{(C6e)}$$

where

V' = traffic volume demand adjusted for increased use of mass transit, veh/hr.

T = number of mass transit passengers during the 1-hour period of interest

P = fraction of passengers who would ordinarily use a private auto were the mass transit facilities not available

avo = average number of passengers per auto

B = increase in number of buses during the hour due to increased use of mass transit, veh/hr.

Table C2. TRIP GENERATION DATA FROM THE COG* REPORT, AND SUGGESTED VALUES FOR USE, AS A FUNCTION OF REGIONAL SHOPPING CENTER SIZE

Center Size 1000's sq. ft.	Number of Centers	"Average Day" Trip Generation Rates (per 1000 sq. ft. per day) From the COG Report Median	Mean	Range	Suggested for Use Median	Mean	Range
300-399	11	40	40	16-62	40	40	20-60
400-499	3	30	34	38-42	40	38	20-60
400-599	10	40	38	18-58	40	38	20-60
700-900	4	36	36	18-52	36	36	20-50
1,000-1,500	2	28	28	26-30	30	30	20-30
Total	30						

*Washington Metropolitan Council of Governments

Equation (C6f) would apply for 8-hour periods.

$$V' = V - \frac{(T)(P)}{(8)(avo)} + \frac{B}{8} \qquad \text{(C6f)}$$

where

T = number of passengers utilizing mass transit during 8-hour period of interest

B = increase in number of buses during 8-hour period, veh/8-hour

3. Calculation of Running Time (RT)

The running time (RT) for a typical vehicle is the sum of the time it takes to approach, enter, move in, park, unpark, move out, exit and depart from the source's parking lot during periods with little congestion, plus any extra time resulting from congestion of the facility during peak usage periods. The time required during periods of little congestion is referred to as the base running time (BRT) and ideally should be provided by the developer. If this estimate is not available, it should be obtained by studying the facility's physical configuration. An example of the procedure used in determining BRT is depicted by the following expressions:

$$\text{Base Approach Time} \approx \frac{\text{(Distance between Entrance and Nearest Intersection on the Access Road, m)}}{\text{(posted speed limit, m/sec)}} \qquad \text{(C7a)}$$

$$\text{Base Entrance Time} \approx \frac{1}{\text{(Main Entrance Gate Capacity, veh/sec)}} \qquad \text{(C7b)}$$

$$\text{Base Movement-In Time} \approx \frac{\text{(Distance from Center of Lot to Main Entrance Measured Along Traffic Lanes, m)}}{\text{(Speed Limit in Lot, m/sec)}} \qquad \text{(C7c)}$$

$$\text{Base Stop, Base Start Time} \approx \text{5-10 sec each depended on angle of parking and lane width} \qquad \text{(C7d)}$$

$$\text{Base Movement-Out Time} = \frac{\text{(Distance from Center of Lot to Main Exit Measured Along Traffic Lanes, m)}}{\text{(Speed Limit in Lot, m/sec)}} \qquad \text{(C7e)}$$

$$\text{Base Exit Time} = \frac{1}{\text{(Main exit gate capacity, veh/sec)}} \qquad \text{(C7f)}$$

$$\text{Base Departure Time} = \frac{\text{(Distance between Main Exit and Nearest Intersection on the Access Road, m)}}{\text{(posted speed limit, m/sec)}} \qquad \text{(C7g)}$$

Typical Base Running Times observed at a limited number of shopping centers in the Washington, D. C. area indicated a Base Running Time of about 270 secs. In a study conducted for EPA at a regional shopping center[9] Base Running Times (running time in and running time out) averaging about 220 secs. were observed.

As a rule, the components of running time most affected by congestion are the movement-in, exit and entrance modes. In the case of unsupervised parking (e.g. shopping centers), increases in movement-in time results from cars searching for the few remaining parking spaces. Table C3 presents a series of correction factors which should be applied to shopping centers and parking lots of various sizes when the accumulation of vehicles in the lots begins to approach or exceed the parking lot capacity. Table C3 is based on information contained in reference 8. Accumulation of vehicles in the lot should be estimated from diurnal use patterns. Limited data which are available[9] indicate that running time begins to increase appreciably when the lot is more than 80 percent occupied. It is, therefore, suggested that Table C3 be applied during

Table C3. GUIDELINES FOR ASSESSING THE IMPACT OF PARKING CAPACITY EXCEEDENCE ON BASE RUNNING TIME

(1)	(2)	(3)	(4)
Gross Leasible Fl. Space 10^3 Ft^2	Parking Spaces Per 1000 ft. of Gr. L. Fl. Sp.	Ave. Daily Arrivals* Per 1000 Ft^2 of Floor Space Per Day which Correction Factor is Needed	Correction Factor (CF) Needed to Compute Overall Traffic Density
300 - 399	< 4	16 arrivals/1000 Ft^2-day	$cf = (\frac{V + .20\ PC^{**}}{V})$
	≥ 4, < 6	23	$(\frac{V + .10\ PC}{V})$
	≥ 6, ≤ 8	25	$(\frac{V + .05\ PC}{V})$
	> 8	Correction Factor not needed	1
400 - 499	< 4	16	$(\frac{V + .20\ PC}{V})$
	≥ 4, < 6	23	$(\frac{V + .10\ PC}{V})$
	≥ 6, ≤ 8	25	$(\frac{V + .05\ PC}{V})$
	> 8	Correction Factor not needed	1
500 - 599	< 4	16	$(\frac{V + .20\ PC}{V})$
	> 4, < 6	23	$(\frac{V + .10\ PC}{V})$
	> 6, < 8	25	$(\frac{V + .05\ PC}{V})$
	> 8	Correction Factor not needed	1

Table C3. GUIDELINES FOR ASSESSING THE IMPACT OF PARKING CAPACITY EXCEEDENCE ON BASE RUNNING TIME (Cont'd)

(1)	(2)	(3)	(4)
Gross Leasible Fl. Space 10^3 Ft^2	Parking Spaces Per 1000 ft. of Gr. L. Fl. Sp.	Ave. Daily Arrivals* Per 1000 Ft^2 of Floor Space Per Day which Correction Factor is Needed	Correction Factor (CF) Needed to Compute Overall Traffic Density
600 - 899	< 4	14	$\left(\frac{V + .20\ PC}{V}\right)$
	$\geq 4, < 6$	20	$\left(\frac{V + .10\ PC}{V}\right)$
	$\geq 6, \leq 8$	21	$\left(\frac{V + .05\ PC}{V}\right)$
	> 8	Correction Factor not needed	1
> 900	< 4	11	$\left(\frac{V + .20\ PC}{V}\right)$
	$\geq 4, < 6$	13	$\left(\frac{V + .10\ PC}{V}\right)$
	$\geq 6, \leq 8$	13	$\left(\frac{V + .10\ PC}{V}\right)$
	> 8	Correction Factor not needed	1

* Daily arrivals = (1/2) (Average Daily Trip Generation Rate)

** PC = parking lot capacity -- the number of parking spaces in the shopping center lot

V = number of vehicles to be accommodated during the hour of interest periods in which the accumulation of vehicles in the parking lots exceeds 80 percent of the lot's parking capacity and there is no supervision of parking. If parking is supervised, additional running time spent in the movement-in mode would occur only if the accumulation of vehicles in the lot exceeded the parking capacity. Extra time would then be required to move to an auxiliary lot. This additional running time, Δ_{MI}, would be estimated using an expression similar to expression (C8).

$$\Delta_{MI} = \frac{\left(\begin{array}{l}\text{Dist. from Center of Main}\\ \text{Lot to Main Lot Exit}\end{array}\right)}{(\text{Posted Main Lot Speed Limit})} + \frac{\left(\begin{array}{l}\text{Dist. between Main Lot}\\ \text{Exit \& Aux. Lot Entrance}\end{array}\right)}{(\text{Posted Speed Limit})}$$

$$+ \frac{\left(\begin{array}{l}\text{Dist. between Aux. Lot}\\ \text{Entrance and Center}\end{array}\right)}{(\text{Posted Speed Limit})} \qquad \text{(C8)}$$

where

Distances are measured along traffic lanes in meters

Posted speed limits are in m/sec

Δ_{MI} = increase in movement-in, time resulting from exceedence of the main parking lot's capacity, sec

Increased running times occur in the exit or entrance modes when volume demand approaches gate capacity. When this happens queues form at the exit (entrance) thereby increasing running times. The increase in running time for each lane of traffic at a gate, i, having no traffic signal may be estimated from queuing theory using Equation (C9).[10]

$$RT_{q_i} = \frac{3600}{c_i} \left(\frac{v_i}{c_i - v_i}\right), \; {}^{v_i}/{}_{c_i} \le .95 \qquad \text{(C9)}$$

where RT_{q_i} = time spent in queue, sec

c_i = entrance or exit capacity of gate i (obtained from developer) veh/hr*

v_i = traffic volume demand entering or leaving at gate i, veh/hr

The parameter "v_i" is obtained by apportioning entering and leaving traffic among gates and lanes. Ideally the apportionment of entering and exiting traffic should be provided by the developer, and should reflect the orientation of the shopping center with respect to the population center. However, if the apportionment is not provided, it may be estimated in one of the following ways:

(a) According to access road capacities.

$$E_i = [E] \frac{\text{(capacity of access road to gate i)}}{\text{(capacity of all access roads)}} \tag{C10}$$

where

E_i = traffic entering gate i during the 1- or 8-hour period of interest, veh/hr

E = total entering traffic during the 1- or 8-hour period of interest, veh/hr

and $$X_i = [X] \frac{\text{(capacity of access road to gate i)}}{\text{(capacity of all access roads)}} \tag{C11}$$

where

X_i = traffic exiting rate from gate i during the 1- or 8-hour period of interest, veh/hr

X = total exiting traffic rate during the 1- or 8-hour period of interest, veh/hr

---

*NOTE: The demand and capacity terms in Eqs. (C9), (C14) and (C15) pertain to the demand and capacity upstream from a constriction (e.g., an intersection or toll booth). For example, if traffic were entering a lot by making a left turn from an access road, the volume of traffic turning left and the capacity of the access road to accommodate this traffic at Level of Service E should be used in the equations.

(b) If access road capacities are unknown, or if more than one gate empties onto the same access road, traffic can be apportioned according to gate capacities.

$$E_i = [E] \frac{\text{(Entrance capacity of Gate i)}}{\text{(Entrance capacity of all Gates)}} \qquad \text{(C12)}$$

and $$X_i = [X] \frac{\text{(Exit capacity of Gate i)}}{\text{(Exit capacity of all Gates)}} \qquad \text{(C13)}$$

To estimate time spent in exit queues, v_i is set equal to X_i and Equation (C9) is used. A similar procedure may be followed for entrance queues if E_i is apportioned directionally on the access road, and the entering traffic volume from each direction is set equal to v_i. For entering traffic, the excess running time spent entering would be the mean value of the excess running time spent entering entrance i from the various directions on the access road. If the entering or exiting traffic at a gate is estimated to be greater than 95 percent of the gate's exiting or entering capacity, the excess running time spent in queues should be approximated using Equation (C14).

$$RT_{qi} = 3600 \left(\frac{20}{c_i}\right) \qquad .95 < v_i/c_i \leq 1 \qquad \text{(C14)}$$

If $v_i/c_i > 1$,

$$RT_{qi} = 3600 \left[\frac{20}{c_i} + \frac{(v_i - c_i)}{2c_i}\right] \qquad v_i/c_i > 1 \qquad \text{(C15)}$$

Excess running time spent entering or exiting from a parking lot with signalized exit/entrances may be estimated using Equation (C16).

$$(RT_q)_i = \left[\frac{(C_y)(c')(1 - G/C_y)^2}{2\,(c' - v)} + \frac{1800\, vC_y^{\,2}}{c'G(c'G - vC_y)}\right]_i \qquad \text{(C16)}$$

where $(RT_q)_i$ = excess running time spent entering or exiting at entrance/exit i, sec

C_y = signal cycle length, sec

c' = unimpeded capacity at a signalized intersection approach, vph

G = amount of green time per signal cycle for the intersection approach of interest, sec

G/C_y = green time to signal cycle ratio, dimensionless

v = traffic demand at the intersection approach of interest, vph

Equation (C16) is adapted from concepts expressed by Newell[11] concerning delay times spent by vehicles at approaches to signalized intersections.

Throughout the shopping center, average excess running time spent in entering and exiting queues is given by Equation (C17).

$$\overline{RT}_q = \frac{\sum_{\text{all}_i} RT_{qi}}{I} \qquad \text{(C17)}$$

where I = total number of exit and entrance gates

Equation (C18) should be used to estimate running time for a typical vehicle-trip during the 1- or 8-hour period of interest if the parking is not supervised.

$$RT = \frac{BRT}{2} + \left[(cF-1)BRT\right]\left[\frac{\text{entering traffic}}{\text{total traffic}}\right] + \overline{RT}_q \qquad \text{(C18)}$$

where

cF = 1 if lot is less than 80% full

If parking is supervised, Equation (C19) should be used instead.

$$RT = \frac{BRT}{2} + \Delta_{MI}\left[\frac{\text{entering traffic}}{\text{total traffic}}\right] + \overline{RT}_q \qquad \text{(C19)}$$

where

$\Delta_{MI} = 0$ if lot is not full

It is necessary to divide the Base Running Time by "2" in Equations (C18) and (C19) since each trip is a one-way trip. Thus, in determining average daily trip generation rate, each vehicle is counted twice. Since the Base Running Time refers to the total time required to enter and leave a shopping center, it should be divided by "2."

B. Estimating Peak Impacts Within or Near the Parking Lot or on Access Roads Removed from the Lot.

Peak concentrations of CO are likely to occur in the vicinity of exit/entrances to the lot, near access roads or at nearby intersections. Traffic at such locations may be characterized as line sources of pollution. Two situations are of interest: the case where traffic flows freely by the receptor; and the case where queues form in the vicinity of the receptor. At traffic lanes within or adjacent to the parking lot, the impact of freely flowing and/or queuing vehicles on CO concentrations in the vicinity of the lanes should be added to estimates obtained using an area source model relating the source's upwind dimension and emission density to CO concentrations and general background levels. More details concerning this procedure are presented in Appendix H. Equation (C2) is used to estimate the appropriate emission density.

$$Q = \frac{(EF)(V)(RT)}{216{,}000A} \quad \text{(C2)}$$

The discussion in Appendix A concerning microscale impact analysis may be used to estimate the impact of freely flowing and/or queuing traffic on nearby CO concentrations. Equation (A11) is used to estimate the impact of freely flowing traffic. If traffic at a signalized intersection is of interest, excess emissions over a finite queue (obtained using Equations (A18) and (A19)) are added to emissions estimated for a line source of freely flowing traffic with Equation (A11). Emissions near a nonsignalized intersection may be approximated with Equations (A20) - (A23) and with Equation (A11).

CIV. Qualitative Guidelines

In addition to the quantitative evaluation procedures developed above, the review of shopping centers as complex emission sources should also include the following considerations which are not presently reducible to quantitative terms:

1. Main entrance/exitways should preferably be on a highly visible local secondary street that feeds into the nearest arterial, so that the transition from highway driving to parking lot driving and vice versa is not too abrupt.

2. Any left turn movement across traffic flow that is used by a significant number of the shopping center patrons is a potentially large congestion point and emission problem.

3. At centers with multiple entrance/exits, the vehicles will generally tend to distribute themselves among the available gates to minimize their running times. However, if unbalanced gate use does

occur, it may be reduced by stationing personnel in the parking area to divert outgoing traffic from the overburdened exit or by the use of traffic information signs.

4. Personnel (including police) may also be effectively used to speed traffic flow during periods of highest congestion.

5. Prior provision for overflow parking in a temporary or remote lot may be an appropriate requirement for centers with anticipated marginal parking capacities.

6. The design of curbed entrances and exit "streets" within the parking lot (but separate from the parking areas) may reduce the interference of exit queues with in-lot movement and move congestion points away from the gates to a more desirable (or controllable) location in the lot.

REFERENCES

(1) U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards; "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 10: Reviewing New Stationary Sources"; EPA-450/4-74-011 (Sept. 1974); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(2) Kunselman, P., H. McAdams, C. J. Domke and M. Williams; "Automobile Exhaust Emission Modal Analysis Model"; EPA-460/3-74-005 (January 1974); National Technical Information Service, Springfield, Va. 22161.

(3) Compilation of Air Pollutant Emission Factors, EPA Publication No. AP-42 (Supplement 5 to the Second Edition); (In Press).

(4) 40 CFR 85; "1975 Federal Test Procedure"; Federal Register 36, No. 128 (July 2, 1971).

(5) Williams, M. E., J. T. White, L. A. Platte and C. J. Domke; "Automobile Exhaust Emission Surveillance -- Analysis of the FY 72 Program"; EPA-460/2-74-001 (February 1974); National Technical Information Service; Springfield, Va. 22161.

(6) Ashby, H. A., R. C. Stahman, B. H. Eccleston and R. W. Hurn; "Vehicle Emissions - Summer to Winter"; Paper No. 741053 presented at the Society of Automotive Engineers Automobile Engineering Meeting; Toronto, Canada (October 21-25, 1974); Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pa. 15096.

(7) Clear, D. R. and M. G. Dolan; Barton-Aschman Assoc., Washington, D. C.; personal communication.

(8) Thayer, S. C. and K. Axetell; "Vehicle Behavior in and Around Complex Sources and Related Complex Source Characteristics: Volume I - Shopping Centers"; EPA-450/3-74-003a (August 1973); National Technical Information Service, Springfield, Va. 22161.

(9) Patterson, R. M., R. M. Broadway, G. A. Gordon, R. G. Orner, R. W. Cass and F. A. Record; "Validation Study of an Approach for Evaluating the Impact of a Shopping Center on Ambient Carbon Monoxide Concentrations"; *EPA-450/3-74-059*; U.S. EPA, Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(10) Hillier, F. S. and Lieberman, G. J.; *Introduction to Operations Research*; Holden-Day, Inc., San Francisco, California (1967); Chapter 10.

(11) Newell, G. F.; "Approximate Methods for Queues with Application to the Fixed Cycle Traffic Light"; *S. I. A. M. Review*; *7* No. 2 (1965).

Additional Data Sources

Books and Reports

Baker, Geoffrey, and Bruno Funaro. Shopping Centers - Design and Operation. Reinhold Publishing Corporation, Progressive Architecture Library. New York City.

Baker, Geoffrey, and Bruno Funaro. Parking. Reinhold Publishing Corporation, Progressive Architecture Library. New York City.

Barton-Aschman Associates, Inc., "Traffic Planning for Shopping Centers" School of Design and Construction, ICSC University of Shopping Centers; Chicago, Illinois (February 1973).

Lynch, Keven. Site Planning. The M.I.T. Press, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Gruen, Victor, and Larry Smith. Shopping Towns U.S.A. - the Planning of Shopping Centers. Reinhold Publishing Corporation, Progressive Architecture Library. New York City.

Institute of Traffic Engineers Technical Committee 5-DD Draft Report, "Shopping Center Access," (1974).

Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board. Traffic Characteristics of Shopping Centers - A Review of Existing Data. Technical Report No. 3, July 1970.

Urban Land Institute. Planning Requirements for Shopping Centers - A Survey. Technical Bulletin 53. Research sponsored by the Research Foundation of the International Council of Shopping Centers.

Automotive Environmental Systems, Inc. A Study of Emissions from Light Duty Vehicles in Six Cities. EPA Document No. APTD-1497. March 1973.

Maryland Bureau of Air Quality Control. Method for Estimating Light Duty Vehicle Emission on a Sub-Regional Basis. Report BAQC-TM 73-107. April 1973.

U. S. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors (Second Edition). EPA Publication No. AP-42. April 1973.

Architectural Record. Building Types Study 432: Shopping Malls in Suburbia. Vol. 151, No. 3. March 1972.

Zoning Ordinances for Various Communities.

Washingtonian Magazine. Supermalls! August 1973, pp. 58-63.

APPENDIX D. METHODS FOR ESTIMATING EMISSIONS IN VICINITY OF SPORTS COMPLEXES

This appendix is intended to provide guidance concerning a more detailed analysis of proposed indirect sources should this be necessary or desirable pursuant to 40 CFR 52.22(b). The materials contained herein are offered as suggestions. Alternate analytical approaches for evaluating the impact of a proposed source may be used if it can be demonstrated that they are more applicable to the source under review.

U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, N. C. 27711

January 1975

APPENDIX D.

METHODS FOR ESTIMATING EMISSIONS IN VICINITY OF SPORTS COMPLEXES

The purpose of this Appendix is to provide a means for assisting air pollution control agencies or developers in estimating vehicular emissions associated with the operation of a sports complex. If stationary sources are of significance, Volume 10 of the "Guidelines for Air Quality Maintenance Planning and Analysis"[1] should be referred to. Emissions estimated using the guidance in this appendix may then be used to estimate the impact of the complex on nearby ambient CO concentrations. The methodology proposed in Appendix D is based largely on information contained in a report[2] prepared for EPA under contract concerning vehicle behavior in and around sports stadiums, and upon observations made during a monitoring study[3] of traffic and ambient CO concentrations conducted for EPA in the vicinity of major league baseball stadiums. The general approach of the proposed methodology is to require prospective developers to submit certain essential information. A second body of information is designated as optional. It would be preferable to have a complete set of optional information supplied by the developer as well. If this is not possible, however, data compiled for EPA[2] for a limited sample of sports stadiums can be substituted. The methodology for estimating emissions is necessarily general. Therefore, the developer should be encouraged to perform a detailed analysis of the impact of the proposed facility using data and methods which are specifically suited for the case under review. If it is necessary to estimate HC and NO_x emissions at the sports complex, emission factors should be obtained for these pollutants as described in Appendix B. Since it is very unlikely that the sports complex (functioning as a sports complex) will attract traffic from 6 - 9 A.M., the impact of the complex on NO_x emissions may be of greatest interest. There is, of course, the possibility that the stadium lots could be used for commuter lots (e.g., Shea Stadium in New York City) during periods in which HC emissions are of interest. In such cases however, the traffic may lose its "event-oriented" attributes associated with large sporting or entertainment events, and the methodology presented in Appendix E on parking lots would be more appropriate.

Section DI of this Appendix summarizes the methodology for estimating total CO emissions resulting from the operation of the complex, emissions which occur in traffic lanes, in the vicinity of congested exit or entrance gates and at nearby intersection approaches. The remaining portions of the Appendix discuss how the methodology presented in Section DI might be implemented.

DI. Procedure for Estimating Emissions Resulting from the Operation of a Sports Complex

1. Obtain estimates for the key design and operating parameters indicated in Table D1.

2. Consider automobiles and buses separately. Estimate appropriate emission factors from modal operation patterns at sports complexes. If this is not possible, use Fig. D1 (and Equation (D4) if necessary) to estimate automobile emission factors. Apply appropriate correction factors for altitude, temperature and percentage of cold starts using Section 4.4 of the Screening Procedure or Supplement 5 to AP-42. Use Supplement 5 (Sections 3.1.4.3 and 3.1.5) to estimate appropriate emission factors for diesel and gasoline-powered buses (in gm/veh-mi). Convert to appropriate units (gm/min-veh) using Fig. D1 and Eq. (D5).

3. If volume (i.e., not volume demand) of automobiles using parking lots is not provided, estimate it using Eq. (D6). If volume of buses using parking lots is not provided, assume it is the same as the number of parking spaces allotted for buses.

4. It is assumed that essentially all traffic arrives at the complex within an hour of the scheduled start and leaves within an hour after the event's conclusion. Therefore, divide the auto and bus traffic volumes by one hour to obtain auto and bus traffic volume demand in vph.

5. It is assumed that maximum emissions occur in the hour following an event's conclusion. Thus, running time is the amount of time it takes to unpark, move out, exit and depart from the facility. Estimate unpark and movement-out time using the source's physical configuration and operating procedures. If stall parking is used (e.g. with buses), estimate unparking and movement-out time with Table D2. Traffic demand in the

remaining running time calculations is assumed to occur entirely within the parking lot emptying time. If traffic distribution through the exit gates is about uniform, use Eq. (D7a) or (D8) - (D8b) to estimate running time spent in exit queues upstream from unsignalized intersections. For signalized intersections use Eq. (D7a) or (D9). If traffic is not evenly distributed, use Eq. (D10) or Eqs. (D11) or (D12) to estimate running time in queues at each gate and then use Eq. (D13) to obtain average running time spent in queues.

6. Combine stadium bus and auto traffic with unrelated traffic and apportion the total among access roads. Use demand-capacity ratios vs. speed relationships depicted in Appendix A to estimate operating speeds on road segments. Departure running time is estimated using Eq. (D15).

7. Obtain total running time required for leaving, using Eq. (D16) and combine this with estimates for volume demand and emission factors in Eqs. (D1) and (D2) to estimate total peak 1-hour emission rate and emission density. This emission density applies for the amount of time required for traffic to dissipate. The remainder of the time the emission density is zero.

8. If the impact of entering traffic at the beginning of an event is of interest, volume demand and emission factors are obtained as before. Running time is the sum of the time spent in the arrival, entering and movement-in and parking modes. Assume arriving vehicles are, unlike departing vehicles, evenly spread out over the hour. Using this assumption, use Eq. (D15) to estimate arrival mode running time.

Equations (D8), (D9), or (D11), (D12), or (D21) should be used in estimating entrance mode running times. Use Eq. (D22) to estimate movement-in and parking times. Total entrance running time is given by Eq. (D23). Use the total entrance running time along with volume demands for autos and buses and emission factors to estimate total emission rate and emission density with Eqs. (D1) and (D2).

9. Refer to the Micro Analysis section in Appendix A to estimate the impact of freely flowing and/or queuing traffic on nearby CO concentrations. The procedure is as follows:

a. Estimate traffic demand for each lane j in road segment i using Eqs. (A12) or (A13). If necessary, adjust the demand for the impact of mass transit using Eqs. (A14) or (A15). Apportion demand among lanes, making sure that Eq. (A2) is satisfied.

b. If the analysis does not concern an at-grade intersection, estimate capacity of the road segment using Eq. (A10) and the lane capacities using Eq. (A16). Check that Eq. (A3) is satisfied. If not, adjust the lane capacities so that Eq. (A3) is satisfied.

c. Determine volume to capacity ratios (v_{ij}/c_{ij}) for each lane. Given the type of road and the average highway speed, use the appropriate one of Figs. A2 - A5 to estimate vehicle operating speeds in each lane.

d. Use Fig. A6 to estimate the speed corrected 1975 emission factor for each lane. For years other than 1975, adjust this factor with Equation (A17). Correct for cold starts and ambient temperatures as needed, using Section 4.4 of the Screening Procedure or Supplement 5 to AP-42.

e. Use Eq. (A11) to estimate the line source emission intensity of freely flowing traffic.

f. For at-grade signalized intersections, use information concerning signal cycle lengths and green time to signal cycle ratios to estimate queue lengths with Eq. (A18). Consider emissions over the queue length to be the sum of those from freely flowing traffic and excess emissions. Emissions elsewhere are attributable to freely flowing traffic. Estimate emissions from freely flowing traffic using Eq. (A11), and excess emissions using Eq. (A19). Alternatively, use the information in Tables A8-A12 directly to estimate appropriate emissions and queue lengths.

g. For non-signalized intersections, estimate the average queue length using Eq. (A20). Use Eq. (A21) to estimate the emission intensity over the queue at the intersection approach. Estimate the distance over which vehicles may accelerate and decelerate using Eq. (A22). The emission intensity over this distance is obtained using Eq. (A23). Use Eq. (A11) to estimate emission intensity elsewhere.

DII. Identification of Key Design and Operating Variables

Table D1 presents the essential and desirable parameters which the developer should supply the control agency so that emissions associated with the operation of the sports complex may be estimated.

Table D1. SPORTS COMPLEX PARAMETERS NEEDED FOR ESTIMATING EMISSIONS

I. Essential Parameters

Parameters	Remarks
Seating capacity	Assumed to be equivalent to peak attendance
Average attendance	Possible sources of information for this parameter include market surveys conducted for new teams or previous experience of established teams moving to new areas
Available parking spaces	This parameter should be broken up into 3 subtotals: a. Spaces available in off-street stadium operated parking lots b. Spaces in other off-street public and private parking lots c. On-street spaces available within 3/4 km and within 1 km of the stadium property
Number and capacity of parking lot gates	This information should be contained on a set of plans or blueprints provided by the developer which present a schematic picture of access roads, complex dimensions and configuration
Surrounding street configurations, capacity and speed limits (within 2 km of stadium)	" " " "
Estimated traffic volume on nearby streets **not** related to stadium activities	This information should be solicited from local and State Highway Depts.
Number of parking spaces allotted for buses	Should be available from parking lot design

Table D1 (continued). SPORTS COMPLEX PARAMETERS NEEDED FOR ESTIMATING EMISSIONS

I. Essential Parameters

Parameters	Remarks
Stadium emptying time	Time after end of an event by which all spectators have reached their parking spaces
Plans or blueprints of the stadium, parking lots and surrounding access roads	Needed to prorate demand among gates and access roads and as an indicator of the complex's size
Green time to signal cycle ratio for each intersection	Needed to estimate traffic capacity at each intersection approach and to estimate queue lengths resulting at each approach
Number of signal cycles per hour at each intersection	Needed to estimate queue lengths at intersection approaches.

II. Desirable Parameters

Parameters	Remarks
Percent of spectators arriving by automobile	
Average vehicle occupancy	
Number of buses	Obtain estimate from local transit authority or bus companies
Estimated order of preference for parking facilities	This is the developers' estimate of the order in which the 3 types of parking facilities are utilized by spectators
Vehicle spacing in queues	Tail pipe-to-tail pipe distance
Distribution of operation modes (i.e. acceleration, deceleration, etc.) for a typical vehicle visiting a sports complex	Useful in obtaining estimates for emission factors

DIII. Estimation of Emissions in the Vicinity of Sports Complexes

Since the usage of sports complexes occurs at discrete times as dictated by the sporting event, traffic is characterized by very heavy demand over relatively short periods and little demand the rest of the time. Consequently, the capacity of nearby (e.g., within 2 km of the stadium property) roads and intersections may be exceeded. Thus, the possibility exists that the worst impact of the sports stadium on CO concentrations may occur relatively far away from the stadium. This possibility means that two separate analyses may be needed:

1. An analysis in the immediate vicinity of the stadium, taking account of emissions within the parking lot and queues at the most congested sections of the parking lot.

2. An analysis of nearby access roads and intersection approaches to determine points at which traffic volume demand approaches or exceeds road capacity.

A. Emissions in the Immediate Vicinity of the Stadium (i.e. Parking Lots)

1. Total Emission Rate and Emission Density

These variables are of interest for two reasons:

(a) to provide a means for relating construction of the sports complex with emission limitations which may be imposed by land use or air quality maintenance plans;

(b) to provide a means for estimating the emission density at the sports complex and the resulting impact on background (or representative) concentrations of CO.

Equations (D1) and (D2) may be used to estimate total emission rate and emission density for the stadium and its surrounding parking lots.

$$Q' = \left[\frac{(EF)(V)(RT)}{216{,}000}\right]_{\text{autos}} + \left[\frac{(EF)(V)(RT)}{216{,}000}\right]_{\text{buses}} \tag{D1}$$

$$Q = \frac{[(EF)(V)(RT)]\ \text{autos} + [(EF)(V)(RT)]\ \text{buses}}{216{,}000A} \tag{D2}$$

where Q' = emission rate, gm/sec

Q = emission density, gm/sec-m^2

EF = emission factor, gm/min-veh

V = traffic volume demand, veh/hr.

RT = average running time, sec

A = contiguous area of the stadium and its surrounding parking lots, m^2

1/216,000 = conversion factor from $\frac{\text{gm-sec}}{\text{min-hr}}$ to gm/sec

The separate terms in Eqs. (D1) and (D2) for buses are probably needed since there is often a large number of buses at events, and frequently these may be separated into segments of the lots reserved for buses. If traffic generated by the source takes less than an hour to dissipate from the source after an event's conclusion, Equations (D1) and (D2) would only apply for that portion of the hour. The rest of the time, the emissions would be zero.

3. Determination of Emission Factors(EF)

(1) Automobiles

Probably the most accurate estimates for emission factors at a sports complex would be obtained if typical driving cycles (i.e. amounts of time and sequences spent in acceleration, deceleration and steady speed modes of travel) were known for sports complexes. A typical driving cycle could then be simulated using the EPA Automobile Exhaust Emission Modal Analysis Model[4] to obtain average trip emission factors which are explicit for sports complexes. This approach has been followed in characterizing emissions at signalized intersections in Appendix A. Unfortunately, there is not yet sufficient data concerning vehicle operating characteristics at sports stadiums to implement this technique elsewhere within a sports complex. Thus, information appearing in Supplement 5 to AP-42[5] which reflects emission factors obtained using the 1975 Federal Test Procedure[6] (FTP) will have to suffice. Figure D1 was obtained using the 1975 FTP emission factors for CO for a national average mix of light-duty vehicles for calendar year 1975 and speed correction factors obtained from Tables 3.1.2-6a and b in Supplement 5. The mix upon which Figure D1 is based is composed of 88 percent cars and 12 percent light-duty trucks. The curve in Figure D1 is also based on the assumption that 20 percent of the vehicle emissions occur from vehicles operating from cold starts with ambient temperatures ranging from 68°F - 86°F at a location near sea level. If the assumption concerning altitude, percentage of cold starts and ambient temperature

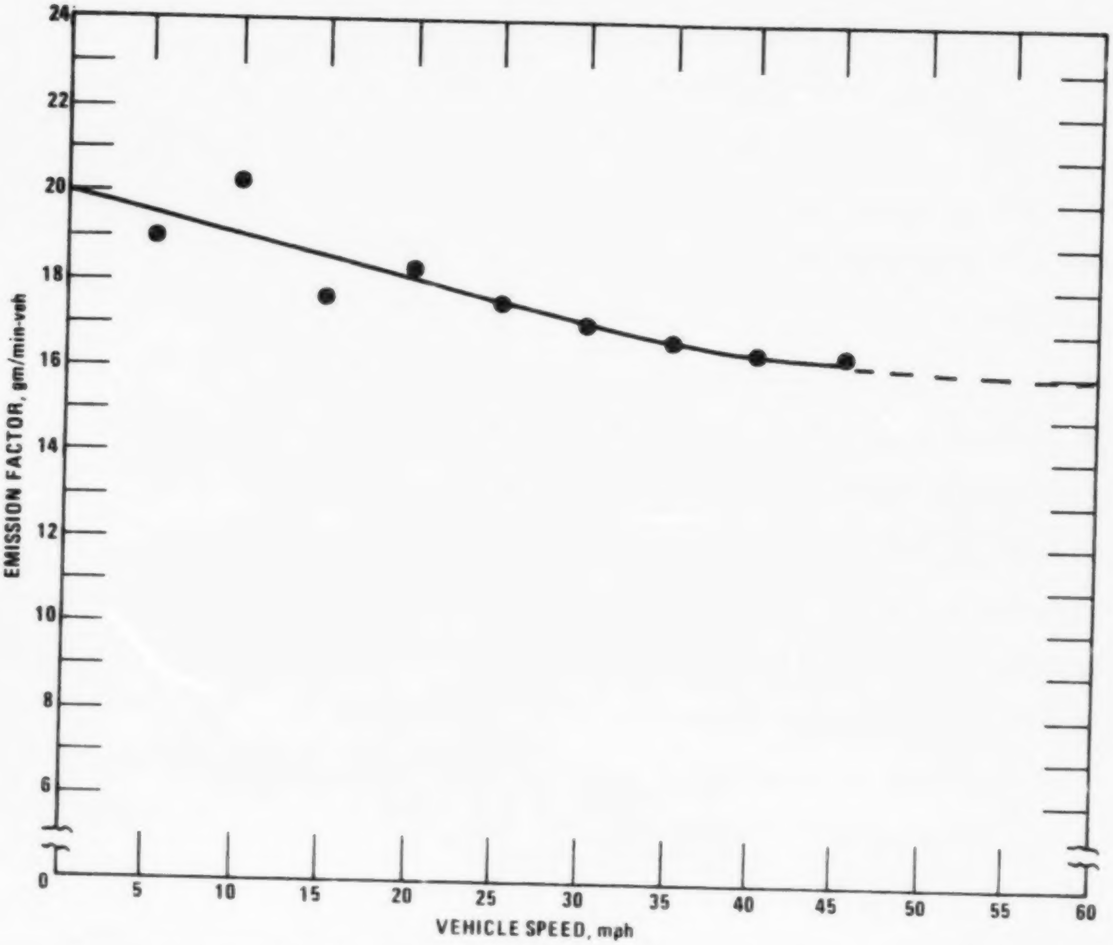


Figure D1. Composite emission factors for carbon monoxide for calendar year 1975.

used in deriving an emission factor are not appropriate, correction factors may be derived using guidance presented in Section 4.4 of the screening procedure or Supplement 5 to AP-42. It should be pointed out that if it is determined that extra emissions attributable to cold starts and cold temperatures only occur for a relatively short time (e.g., 4 minutes), higher emission factors should be used only until a typical vehicle becomes warm. The emission factors obtained for 1975 with Figure D1 can be adjusted for other years by using Equation (D4).

$$EF = \frac{(\text{Corrected Value from Fig. D1})\ (ef)}{55} \qquad (D4)$$

where ef = the emission factor for the year of interest obtained from Table A3, Appendix A, gm/mi-veh

"55" = the emission factor in Table 3.1.1-1 which is applicable for 1975, gm/mi-veh

(2) Buses

In the absence of modal emission data for buses at sports complexes, Sections 3.1.4.3 and 3.1.5 in Supplement 5 to AP-42[5] may be used to provide emission factors (in gm/mi) for heavy-duty gasoline and diesel-powered vehicles respectively. There is no differentiation with respect to model year for diesel emissions. It should suffice for the purpose of this analysis to assume average emission factors suitable for the 1970-73 model years. Once the appropriate emission factors for gasoline and diesel-powered buses are estimated from AP-42, a bus emission factor suitable for use in Eqs. (D1) and (D2) can be calculated using Equation (D5).

$$EF = \frac{(\text{Fig. D1 Value})\left[(\#\text{Gas. Buses})(ef)_g + (\#\text{Diesel Buses})(ef)_d\right]}{(\text{Total \# of Buses})(ef)} \qquad (D5)$$

where $(ef)_g$ is the estimated emission factor for heavy duty gasoline powered vehicles as determined from Section 3.1.4.3 in Supplement 5 to AP-42, gm/mi-veh

and $(ef)_d$ is the estimated emission factor for heavy duty diesel powered vehicles as determined from Section 3.1.5 in Supplement 5 to AP-42, gm/mi-veh

(ef) is the emission factor for light duty vehicles (gm/mi-veh), estimated from Table A3 or from Supplement 5 to AP-42.[5]

It is assumed in Equation (D5) that the variation of heavy duty vehicle CO emission factors with speed is similar to those for light duty vehicles.

C. Determination of Traffic Volume Demand (V)

(1) Automobiles

Total volume of automobiles utilizing parking facilities in the vicinity of the stadium may be estimated using Eq. (D6).

$$V' = \frac{(A)(P)}{avo} \qquad (D6)$$

where V' = number of autos using parking facilities, vehicles

A = attendance. For peak use periods this can be considered equal to seating capacity

P = percent of spectators arriving by auto

avo = average vehicle occupancy for automobiles

The attendance term (A) should be estimated from the stadium seating capacity. This parameter should be required from the developer. The percent of spectators arriving by auto (P) and the average vehicle occupancy terms (avo) in Eq. (D6) should, ideally, be provided by the developer on the basis of the local situation and practices. If this is not possible however, most commonly accepted design values are that 88% of the spectators come by car with an average vehicle occupancy of 3.5 persons/auto for football and 2.5 persons/auto for baseball.[2] For events other than football and baseball games and for facilities other than outdoor stadiums, the developer should be required to provide documented estimates of the percent of spectators arriving by automobile and the average vehicle occupancy.

Automobile traffic volume, as determined by Eq. (D6), is the sum of vehicles parked in the stadium lots, on nearby streets and in privately operated lots. Parking capacities for each type of facility within 1 km of the stadium site should be obtained from the developer in order to estimate localized high levels of CO. In addition, an order of parking preference should be indicated. Unless otherwise indicated, the order of preference should be: stadium lots, on-street parking and privately owned parking lots.[2] Under such an order of preference, it should be assumed that the stadium lots fill up first, followed by the on-street parking spaces and finally by privately-operated lots, until the total traffic accommodated is equal to V'. For purposes of assessing peak impacts on CO concentrations at exits or entrances or within parking lots, only analyses of off-street parking facilities are needed. On-street parking will be assessed in evaluating the impact of the sports facility's operation on nearby access roads and at intersections.

To convert traffic volume to traffic volume demand for use in Eqs. (D1) or (D2) it is assumed that essentially all traffic will arrive or depart from the lots within an hour's time. Thus, even if traffic persists for less than an hour at a somewhat higher flow rate, the net effect will be the same in terms of emissions, providing the actual lot emptying and filling times are used in computing typical automobile running times.

(2) Buses

Estimates for the number of buses (B) expected at an event should be obtained from the developer or promoter. If this estimate cannot be obtained directly, it could be made from the number of parking spaces allotted for buses. It seems reasonable to assume that the most heavily attended events would be the ones at which the number of buses would approach the parking capacity for buses. Once the number of buses is determined, the same rationale as was applied for autos should be used to obtain the bus volume demand (veh/hr) for use in Eqs. (D1) and (D2).

D. Determination of Running Times (RT)

In the procedure described below for estimating running time, it is assumed that automobiles and buses park in separate lots or sections of lots, and do not use the same exit/entrance gates. Consequently, separate analyses are performed for automobiles and buses. If these assumptions were not true, the average running times for autos and buses would be the same, and the total vehicular volume using off-street parking (i.e. V' + B) should be used in the methodologies described below for estimating running times spent in the exit and entrance modes. In any case, it is probably advisable to consider total vehicular volume in estimating running times in the arrival and departure modes on access roads.

(1) Automobiles

Since it is assumed the peak 1-hour impact of a sports complex occurs shortly after an event's conclusion, the running time which should be used in Equations (D1) and (D2) is the time it takes an automobile to unpark, move out to an exit queue, exit and depart. Unless there is evidence to the contrary, for conventional lots running times in the unpark and movement-out modes $(RT)_{mo}$ should be assumed as being the distance measured along traffic lanes from the center of the lot to the main exit divided by a vehicle speed characteristics of level of service E.* Running times in the unpark and movement-out modes may be substantially longer for lots with "stall parking" (i.e. where each vehicle does not have free access to an exit lane). Table D2 expresses typical waiting times before vehicles parked in such a manner can gain free access to exit lanes.[2] Waiting times are not synonymous with running times, however, since some people may wait in their cars with the engine off.

---

*This speed is approximately 2.25 m/sec (5 mph) for downtown streets and 6.75 m/sec (15 mph) for major streets.

Table D2. RUNNING TIMES FOR EXIT FROM PARKING STALLS

(1) Ave. cars/stall	(2) Ave. waiting time, sec.	(3) Assumed $(RT)_{mo}$ running time, sec.
2	4.98 (S.E.T.)[+]	4.98 (S.E.T.) (F)
3	8.28 (S.E.T.)	8.28 (S.E.T.) (F)
4	10.74 (S.E.T.)	10.74 (S.E.T.) (F)
5	12.60 (S.E.T.)	12.60 (S.E.T.) (F)
6	14.10 (S.E.T.)	14.10 (S.E.T.) (F)
7	15.3 (S.E.T.)	15.3 (S.E.T.) (F)

[+] S.E.T. = stadium emptying time, a design figure provided by the developer for the number of minutes after the end of an event it takes all spectators to reach their vehicles.

In Column (3) Table D2, "F" is the fraction of waiting time spent with the engine running.

Average running time in the exit mode can be estimated using Equation (D7a).

$$\overline{RT}_o = 60 \left[\frac{\dfrac{(\text{auto traffic in lot})}{(\text{\# of auto exit lanes})(\text{ave. capacity per lane})} - \text{S.E.T.}}{2} \right] \qquad \text{(D7)}$$

or

$$\overline{RT}_q = 30 \left[\frac{\text{(auto traffic in lot)}}{\text{(\# of auto exit lanes) (ave. capacity per lane)}} - \text{S.E.T.} \right] \qquad \text{(D7a)}$$

where $\overline{RT}_q$ = average running time spent in exit mode, sec

"60" = conversion factor from min. to sec.

"1/2" = factor to obtain average running time in exit mode

ave. capacity per lane = vehicles/min.

S.E.T. = stadium emptying time, min.

The first term within the square brackets in Eq. (D7a) represents the parking lot emptying time (P.L.E.T.). As the Stadium Emptying Time approaches the Parking Lot Emptying Time, Eq. (D7a) becomes unsatisfactory. If $\overline{RT}_q$ is estimated to be less than 30 sec. using Eq. (D7a) (as might happen for sparsely-attended events), PLET-SET < 1 min. and it is assumed that the condition of random arrivals at the exit queues is met. In such cases, average running time spent in exit queues at non-signalized intersections may be estimated using Eq. (D8) - (D8b).[10]

$$\overline{RT}_q = \frac{60}{c} \left[\frac{v}{c-v}\right], \; v/c \le .95 \qquad \text{(D8)}$$

or

$$\overline{RT}_q = 1200/c, \; .95 < v/c \le 1 \qquad \text{(D8a)}$$

or

$$\overline{RT}_q = 1200/C + 3600 \left(\frac{v-c}{2c}\right), \quad v/c \geq 1 \qquad \text{(D8b)}$$

where c = total exit capacity = (# of exit lanes) (ave. exit lane capacity), veh/min.

v = traffic volume demand (not the same as V), veh/min.

"60" = conversion factor from min. to sec in Eq. (D8). In Eq. (D8b), "3600" is the number of seconds in the period in which demand exceeds capacity.

If Equation (D7a) cannot be used and the exits have traffic signals, excess running time spent in queues upstream from signalized intersections should be estimated. For such cases, Equation (D9) may be used instead of Equation (D8).[11]

$$\overline{RT}_q = \left[\frac{(\overline{C}_y)(\overline{c}')(1-\overline{G/C_y})^2}{2(\overline{c}' - \overline{v})} + \frac{1800\,\overline{v}\,\overline{C}_y^{\,2}}{\overline{c}'\,\overline{G}(\overline{c}'\,\overline{G} - \overline{v}\,\overline{C}_y)}\right] \qquad \text{(D9)}$$

where $\overline{RT}_q$ = average excess running time spent in queues, sec

$\overline{C}_y$ = average signal cycle length at each exit, sec

$\overline{c}'$ = mean unimpeded capacity for each of the exits, vph

$\overline{G}$ = mean amount of green time per signal cycle for each exit gate

$\overline{G/C_y}$ = mean green time to signal cycle ratio at each exit

$\overline{v}$ = mean traffic demand at each exit, vph.

In deriving Equations (D7a), (D8) and (D9), it was assumed that traffic is approximately evenly distributed among exit gates. Frequently this assumption may be invalid. It would be necessary to apportion traffic among the exit gates and apply Equations (D10), (D11) or (D12) as appropriate for each exit gate i.

$$RT_{qi} = 30 \left[\frac{\text{(auto traffic at Gate i)}}{\text{(\# of auto exit lanes at i) (ave. lane capacity)}}\right] \text{-S.E.T.} \qquad \text{(D10)}$$

or

$$RT_{qi} = \frac{60}{c_i}\left[\frac{v_i}{c_i - v_i}\right], \; v_i/c_i \leq .95 \qquad \text{(D11)}$$

or

$$RT_{qi} = 1200/c_i, \; .95 < v_i/c_i \leq 1 \qquad \text{(D11a)}$$

or

$$RT_{qi} + 1200/c_i + 3600\left[\frac{v_i - c_i}{2c_i}\right], \; v_i/c_i > 1 \qquad \text{(D11b)}$$

where

c_i = gate capacity at i, veh/min.

v_i = traffic demand through gate i, veh/min.

$$(RT)_{qi} = \left[\frac{(C_y)(c')(1-G/C_y)^2}{2(c'-v)} + \frac{1800\; v\; C_y^{\;2}}{c'G(c'G-vC_y)}\right]_i \qquad \text{(D12)}$$

where the terms are as defined for Equation (D9), except that they are explicit for exit (approach) i. Average running time spent in queues would then be:

$$\overline{RT}_q = \frac{\sum_{\text{all } i} RT_q}{I} \tag{D13}$$

Running time in the departure mode ($(RT)_D$) can be estimated by apportioning total stadium traffic onto the network of access roads and determining the resulting demand to capacity ratios on the road segments between the sports complexes and the nearest intersections. Traffic which is unrelated to the stadium should be included in the estimate of traffic volume demand on these road segments.

The total stadium traffic volume is the sum of off-street and on-street parking. This total stadium volume is converted to volume demand (for the purpose of estimating running time only) by using Equation (D14).

$$V_{TOT} = 60 \left[\frac{V' + B + V'_o}{(P.L.E.T.)} \right] \tag{D14}$$

where V_{TOT} = total demand from all stadium traffic, veh/hr

V' = autos using off street parking, veh

B = buses present, veh

V'_o = autos using on-street parking, veh

"60" = conversion factor from min^{-1} to hr^{-1}

P.L.E.T. = parking lot emptying time, min.

"V_{TOT}" is then apportioned among access roads and added to the non-stadium traffic on each road segment to obtain an estimate of the traffic volume demand for that road segment. This segment's total demand is divided by its capacity in the appropriate direction to obtain a demand-capacity ratio. Operating speed can then be estimated using the appropriate one of Figures A2-A5 in Appendix A. If the demand-capacity ratio exceeds "1", assume an operating speed of 5 mph (2.25 m/sec). The average amount of running time spent in the departure mode is thus:

$$(\overline{RT})_D = \frac{\sum\limits_{\text{all } i} \frac{d_i}{(\text{speed})_i}}{I} \tag{D15}$$

where $(RT)_D$ = sec

d_i = distance along road segment i to the nearest intersection, m

$(\text{speed})_i$ = average operating speed on road segment i, m/sec

I = total number of road segments immediately adjacent to sports complex

Total running time for use in estimating the 1-hr. impact of a sports complex is given in Eq. (D16).

$$(RT)_x = (RT)_{mo} + \overline{RT}_q + \overline{RT}_D \tag{D16}$$

where

$(RT)_x$ = running time required to move to an exit queue line, exit and depart, sec.

(2) Buses

The procedure for estimating bus running times when buses are segregated from autos is exactly the same as for autos except that in the movement out and exit modes, only buses are considered. As indicated above, both autos and buses may have to be considered in the departure mode. $(RT)_{mo}$ is estimated the same way as for autos, except that the fraction "F" in Table D2 may be different to reflect different operating procedures for buses. Eqs. (D7) - (D13) may be applied to estimate $\overline{RT}_q$ if one considers bus traffic, bus exit lanes and bus exit lane capacities. Equations (D14) - (D16) should be applied as is to estimate bus departure and total running times.

E. Entrance Running Times

If it is of interest to estimate vehicle running times during entrance modes, identical values of "EF" and "V" should be used in Equations (D1) and (D2) as were used in estimating exit emissions. Vehicle arrivals are likely to be considerably more spread out than departures. Observations[3] have indicated however, that under most circumstances essentially all spectators arrive within an hour before the start of an event. Hence, arrivals are apportioned over a 1-hour period. Arrival time is the sum of time spent in the arrival, entrance, movement-in and parking modes.

(1) Arrival Mode

Equation (D15) should be used to estimate running time spent in the arrival mode $(RT)_A$. The total volume demand from all stadium traffic, which must be apportioned among access roads and added to traffic unrelated to the stadium using these roads, should be estimated using Eq. (D17) rather than (D14).

$$V_{TOT} = V' + B + V'_o \qquad (D17)$$

(2) Entrance Mode

Running time in the entrance mode at an unsignalized entrance is calculated using equations (D8) or (D11) if v/c is less than .95. If $.95 < v/c \leq 1.$, Eqs. (D8a) or (D11a) should be used. If the entrances are signalized, Equations (D9) or (D12) should be used instead to estimate excess running time spent in entrance queues. If v/c exceeds 1, then the entrances are operating at full capacity for the entire hour and vehicles will be entering the lot for more than an hour. The amount of time for the lot to fill is given by Eq. (D18).

$$t = \frac{\text{(auto traffic vol.)}}{\text{(\# of auto entrance lanes)(Capacity per auto entrance lane)}} \qquad (D18)$$

where auto traffic volume is the number of vehicles ultimately entering the lot (maximum = lot capacity)

capacity is in veh./min

t is in minutes.

Since it is assumed that no vehicles arrive after the event begins, the maximum length of the queue occurs at the beginning of the event (i.e. at the end of the hour preceding the event) and is estimated using Eq. (D19).

$$M = \frac{t-60}{c} \tag{D19}$$

Since the minimum queue length which occurs is zero and this occurs at the beginning of the hour preceding the event and constantly builds up to "M," the average queue length is:

$$\overline{M} = M/2 = \frac{60\ (v-c)}{2} \tag{D20}$$

Therefore, the typical running time for vehicles in an entrance queue may be estimated using Eq. (D21).

$$RT = \frac{3600\ (v-c)}{2c} \tag{D21}$$

where RT is in seconds

3600 is the number of secs. in which demand exceeds capacity.

(3) Movement-in and Parking Modes

Supervised parking is assumed, and $(RT)_{MI}$ may be estimated using Eq. (D22).

$$(RT)_{MI} = \frac{\left(\text{Dist. along traffic lanes from entrance to the center of the lot, m}\right)}{(\text{Speed limit in lot, m/sec})} \qquad \text{(D22)}$$

The procedures outlined by Eqs. (D8), (D9), (D11), (D18) - (D22) may be repeated for autos and buses if there are separate bus lots. The running time used in Equations (D1) and (D2) to estimate entrance emissions is given in Eq. (D23).

$$(RT)_E = (RT)_A + \overline{RT}_q + (RT)_{MI} \qquad \text{(D23)}$$

DIV. Estimating Peak Impacts Within or Near the Parking Lot or on Access Roads Removed from the Lot

Peak concentrations of CO are likely to occur in the vicinity of exit/entrances to the lot, near access roads or at nearby intersections. Traffic at such locations may be characterized as line sources of pollution. Two situations are of interest: the case where traffic flows freely by the receptor; and the case where queues form in the vicinity of the receptor. At traffic lanes within or adjacent to the parking lot, the impact of freely flowing and/or queuing vehicles on CO concentrations in the vicinity of the lanes should be added to estimates obtained using an area source model relating the source's upwind dimension and emission density to CO concentrations and general background levels. More details concerning this procedure are presented in Appendix H. Equation (D22) is used to estimate the appropriate emission density.

$$Q = \left[\left[\frac{(EF)(V)(RT)}{216{,}000\ A} \right]_{\text{cars}} + \left[\frac{(EF)(V)(RT)}{216{,}000\ A} \right]_{\text{buses}} \right] (T) \qquad \text{(D-22)}$$

where T = hours required for traffic to clear out after an event.

If $T > 1$, it is set equal to "1."

The discussion in Appendix A concerning microscale impact analysis may be used to estimate the impact of freely flowing and/or queuing traffic on nearby CO concentrations. Equation (A11) is used to estimate the impact of freely flowing traffic. If traffic at a signalized intersection is of interest, excess emissions over a finite queue (obtained using Equations (A18) and (A19)) are added to emissions estimated for a line source of freely flowing traffic with Equation (A11). Emissions near a non-signalized intersection may be approximated with Equations (A20) - (A23) and with Equation (A11).

DV. Qualitative Design Guidelines

In addition to the quantitative procedure for estimating automotive emissions in the vicinity of sports complexes, there are several qualitative guidelines which, if observed, should lessen congestion and therefore emissions.

1. Efforts should be made to schedule events so that beginnings and endings do not coincide with periods which ordinarily have heavy traffic in the vicinity of the complex.

2. Conflicts between large numbers of pedestrians and traffic, both concentrated in the same time frame and in the area of the complex

can cause substantial increases in vehicle running times. The interruption of traffic flow can be minimized by extensive use of grade separations--bridges, ramps, underpasses--and by close-in curb frontage for high volume discharge and pickup of passengers.

3. Temporary traffic controls, particularly reverse-flow one-way streets, can be very effective for increasing access route capacities in the vicinity of the sports complex. These traffic controls may be particularly important for complexes that are located in built-up downtown areas where lanes cannot be added to existing streets.

4. The developer should provide plans for expected traffic circulation patterns around the stadium. These should be checked for no left turn movements across traffic; right turns in and out for garage or parking lot traffic; maximum use of one-way and divided streets, and two-lane exits from parking lots onto streets.

5. Traffic information signs should be prominently displayed to improve traffic movement.

REFERENCES

(1) U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards; "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 10: Reviewing New Stationary Sources"; EPA-450/4-74-011; (Sept. 1974); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(2) Thayer, S.D. and K. Axetell, Jr.; "Vehicle Behavior in and Around Complex Sources and Related Complex Source Characteristics; Volume III-Sports Stadiums"; EPA-450/3-74-003-C; National Technical Information Service, Springfield, Va. 22161.

(3) Bach, W.D., B.W. Crissman, C.E. Decker, J.W. Menear, P.P. Rasberry, and J.B. Tommerdahl; "Carbon Monoxide Measurements in the Vicinity of Sports Stadiums"; EPA-450/3-74-049; (July 1973); U.S. EPA, Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(4) Kunselman, P., H.T. McAdams, C.J. Domke and M. Williams; "Automobile Exhaust Emission Modal Analysis Model"; EPA-460/3-74-005; (January 1974); National Technical Information Service, Springfield, Va. 22161.

(5) Compilation of Air Pollutant Emission Factors, EPA Publication No. AP-42 (Second Edition); (Supplement #5, In Press).

(6) 40 CFR 85; "1975 Federal Test Procedure"; Federal Register 36, No 128; (July 2, 1971).

(7) Williams, M.E., J.T. White, L.A. Platte and C.J. Domke; "Automobile Exhaust Emission Surveillance--Analysis of the FY 72 Program"; EPA-460/2-74-001; (February 1974); National Technical Information Service, Springfield, Virginia 22161.

(8) Ashby, H.A., R.C. Stahman, B.H. Eccleston and R.W. Hurn; "Vehicle Emissions--Summer to Winter"; Paper No. 741053 presented at the SAE Automobile Engineering Meeting; Toronto, Canada (Oct. 21-25, 1974); Society of Automotive Engineers, Inc.; 400 Commonwealth Drive, Warrendale, Pa. 15096.

(9) Highway Research Board; Special Report 87; Highway Capacity Manual 1965, National Academy of Sciences - National Research Council, Washington, D.C.; (1965).

(10) Hillier, F.S. and G.J. Lieberman; Introduction to Operations Research; Holden-Day, Inc.; San Francisco, Ca. (1967); Ch. 10.

(11) Newell, G.F.; "Approximate Methods for Queues with Application to the Fixed Cycle Traffic Light"; SIAM Review 7 No. 2, (1965).

APPENDIX E. METHOD FOR ESTIMATING EMISSIONS IN VICINITY OF MUNICIPAL PARKING LOTS

This appendix is intended to provide guidance concerning a more detailed analysis of proposed indirect sources should this be necessary or desirable pursuant to 40 CFR 52.22(b). The materials contained herein are offered as suggestions. Alternate analytical approaches for evaluating the impact of a proposed source may be used if it can be demonstrated that they are more applicable to the source under review.

U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, N. C. 27711

January 1975

APPENDIX E.

METHOD FOR ESTIMATING EMISSIONS IN VICINITY OF MUNICIPAL PARKING LOTS

The purpose of this appendix is to provide a means for assisting air pollution control agencies or developers to estimate vehicular emissions resulting from the operation of parking facilities. The estimated emissions will subsequently be used to estimate ambient CO concentrations in the vicinity of the parking facility. The methodology proposed herein is largely based on information contained in a report for EPA concerning vehicle behavior in and around parking facilities and its relationship to readily identifiable design characteristics in the parking facility.[1] Appendix E first presents in Section E1 a procedure which may be used to estimate emissions from a parking lot. The remaining sections in the appendix describe how the procedure identified might be implemented.

EI. Procedure for Estimating Emissions in the Vicinity of a Municipal Parking Lot

1. Obtain estimates for the key design and operating parameters indicated in Table E1.

2. Estimate appropriate emission factors for the parking lot by noting driving cycle patterns and applying EPA's Automobile Exhaust

Emission Modal Analysis Model. If this is impractical, assume the driving cycle used in the 1975 Federal Test Procedure applies, and use Fig. E1 and, if necessary, Eq. (E2) to estimate a CO emission factor. Correction factors for cold ambient temperatures, altitude and percentages of vehicles operating from cold starts may be estimated using guidance in Section 4.4 of the screening procedure or Supplement 5 to AP-42.

3. Use Eqs. (E4) and (E5), or (E7) and (E7a), plus Eq. (E6) to estimate traffic volume demand for the period of interest.

4. Estimate base running time from the source's physical configuration and operating policies, as illustrated in expressions (E8a)-(E8g). Use Eqs. (E14a) and (E14b) or (E16a) and E16b) to apportion exit and entrance traffic among the source's gates. Use Eq. (E10), (E11), or (E12) to estimate excess running time spent in each exit and entrance queue at self-parking facilities having unsignalized gates. If a facility's gates have traffic signals, use Eq. (E13) for this purpose. Use Eq. (E16c) to estimate average excess running time spent in queues at self-parking facilities. Usually there is no excess running time in queues for attendant-operated facilities. Use Eq. (E9) to estimate running time.

5. Estimate emission density using Eq. (E1).

6. Refer to the microanalysis section in Appendix A to estimate the impact of freely flowing and/or queuing traffic on nearby CO concentrations. The procedure is as follows:

a. Estimate traffic demand for each lane j in road segment i using Eqs. (A12) or (A13). If necessary, adjust the demand for the impact of mass transit using Eqs. (A14) or (A15). Apportion demand among lanes, making sure that Eq. (A2) is satisfied.

b. If the analysis does not concern an at-grade intersection, estimate capacity of the road segment using Eq. (A10) and the lane capacities using Eq. (A16). Check that Eq. (A3) is satisfied. If not, adjust the lane capacities so that Eq. (A3) is satisfied.

c. Determine volume to capacity ratios (v_{ij}/c_{ij}) for each lane. Given the type of road and the average highway speed, use the appropriate one of Figs. A2-A5 to estimate vehicle operating speeds in each lane.

d. Use Fig. A6 to estimate the speed corrected 1975 emission factor for each lane. For years other than 1975, adjust this factor with Equation (A17). Use Eq. (A17a) to correct for cold starts and ambient temperature, as needed.

e. Use Eq. (A11) to estimate the line source emission intensity of freely flowing traffic.

f. For at-grade signalized intersections, use information concerning signal cycle lengths and green time to signal cycle ratios to estimate queue lengths with Eq. (A18). Consider emissions over the queue length to be the sum of those from freely flowing traffic and excess emissions. Elsewhere, emissions are attributable to freely flowing traffic. Estimate emissions from freely flowing traffic using Eq. (A11), and excess emissions using Eq. (A19). Alternatively, use the information in Tables A8-A12 directly to estimate appropriate emissions and queue lengths.

g. For non-signalized intersections, estimate the average queue length using Eq. (A20). Use Eq. (A21) to estimate the emission intensity over the queue at the intersection approach. Estimate the distances over which vehicles may accelerate and decelerate using Eq. (A22). The emission intensity over this distance is obtained using Eq. (A23). Use Eq. (A11) to estimate emission intensity elsewhere.

EII. Key Design and Operating Parameters

The general approach of this methodology is to require prospective developers to furnish certain essential information. A second set of information is identified as desirable if available. If a developer is unable to provide this second body of optional information, data compiled for a limited number of parking facilities in a report prepared for EPA[1] or estimation techniques described in this appendix will have to suffice. The methodology for estimating emissions and, ultimately, air quality is necessarily general. Therefore, the developer should be enccuraged to use data and methods which are specifically applicable for the area and peculiar to the facility under consideration.

Table E1 presents information which should be provided by a developer in order to estimate emissions from a parking facility. The parking space capacity parameter in Table E1 is of greater importance for parking facilities than for other types of indirect sources, because the amount of traffic using the facility is more dependent on this parameter than is the case with other indirect sources. This dependence arises because, unlike other indirect sources, the parking facility is not the object of a trip. Rather, it serves to accommodate traffic wanting to visit nearby attractions. Consequently, assuming there is a need for a parking facility, the peak amount of traffic utilizing it is largely determined by its parking space capacity.* The type of facility (garage or open lot) is primarily of interest in relating emissions to ambient CO concentrations. For indirect source--parking management review only outdoor concentrations are of interest. The type of parking utilized is of importance in estimating typical vehicle running times. Generally, running times are diminished with attendant-parking. The physical layout and exit capacities are of importance in apportioning emissions about the facility and in determining running times when vehicle use rates approach exit/entrance capacity. The type of area in which the facility is located to a large extent determines the diurnal pattern of use rates and enables a more informed estimate of 1 and 8-hour peak use rates to be made. Direct estimates of peak 1-hour and 8-hour rates and base running times are also highly desirable. Data concerning the surrounding road network are of interest in determining whether the lot's presence is enough to cause the impact at nearby intersections to become intolerable.

---

*This would not necessarily be true however, if the lot was a multi-purpose one, such as a sports stadium parking lot which was also used to park commuting traffic. In such cases, a more direct estimate of peak traffic volume demand would be needed.

Table 1. PARKING FACILITY PARAMETERS NEEDED FOR AIR QUALITY IMPACT ANALYSIS

I. Essential Parameters

Parameter	Remarks
Parking Space Capacity	
Type of Facility	Garage or open lot
Type of Parking	Attendant or self parking
Number and capacity of exits/entrances, physical size and layout as determined from plans or blueprints	Available from plans for the facility denoting the configuration of entrance/exits and access roads. In the case of attendant-operated facilities capacity is determined by the number of attendants on duty.
Type of area in which facility is located	For example, central shopping district, entertainment district, fringe areas serving commuters, etc.
Diurnal Use Rate Patterns	
Traffic Volume Demand on Access Roads and its Diurnal Variation	
Access Road Capacities	
Number of Parking Attendants Employed	
Green time to signal Cycle Ratio at Nearby Intersection Approaches	Needed to estimate approach capacities at intersections and to estimate queue lengths when the signal is red.
Number of Signal Cycles per Hour	Needed to estimate queue lengths during red signal phases.

Table 1 (continued) PARKING FACILITY PARAMETERS NEEDED FOR AIR QUALITY IMPACT ANALYSIS

II. Desirable Parameters, if Available

Parameter	Remarks
Peak Use Rate	Vehicles/hour
Base Running Time	Sec, This is a function of parking space configuration (e.g. 90°, 45°, etc.) and whether the facility uses self-or attendant-parking, and physical configuration.

EIII. Estimation of Emissions from Parking Facilities

The approach taken in estimating the peak impact of parking facility emissions on ambient CO concentrations is to superimpose estimates obtained with a line source model (to denote contributions of sources passing in the immediate vicinity of the receptor) upon those obtained with an area source model (denoting emissions arising from overall activity within the facility). Consequently, it is necessary to express emissions in two ways:

(1) As emission density to denote overall activity generated by the indirect source, and

(2) As a line source of emissions, such as those which might be found in the vicinity of exit or entrance queues, on access roads or at nearby intersection approaches.

A. Emission Density Calculations

Equation (E1) expresses the technique used to estimate area source emission density.

$$Q = \frac{(EF)(V)(RT)}{216{,}000\ A} \qquad \text{(E1)}$$

where

Q = emission density, gm/sec-m^2

EF = average emission factor gm/min-veh

V = traffic volume demand veh/hr

RT = average running time spent per trip* within the facility during any given period of time, sec

A = area of the facility, m^2

1/216,000 = conversion factor from $\frac{\text{gm-sec}}{\text{min-hr}}$ to gm/sec.

Total emission rate for the parking lot could be estimated using Equation (E1a)

$$Q = \frac{(EF)(V)(RT)}{216{,}000} \qquad \text{(E1a)}$$

where

Q = gm/sec

Equation (E1a) may be of particular use for estimating emissions from parking garages where emissions are released through a vent.

---

*One vehicle visiting the parking lot makes 2 trips--one coming, one going.

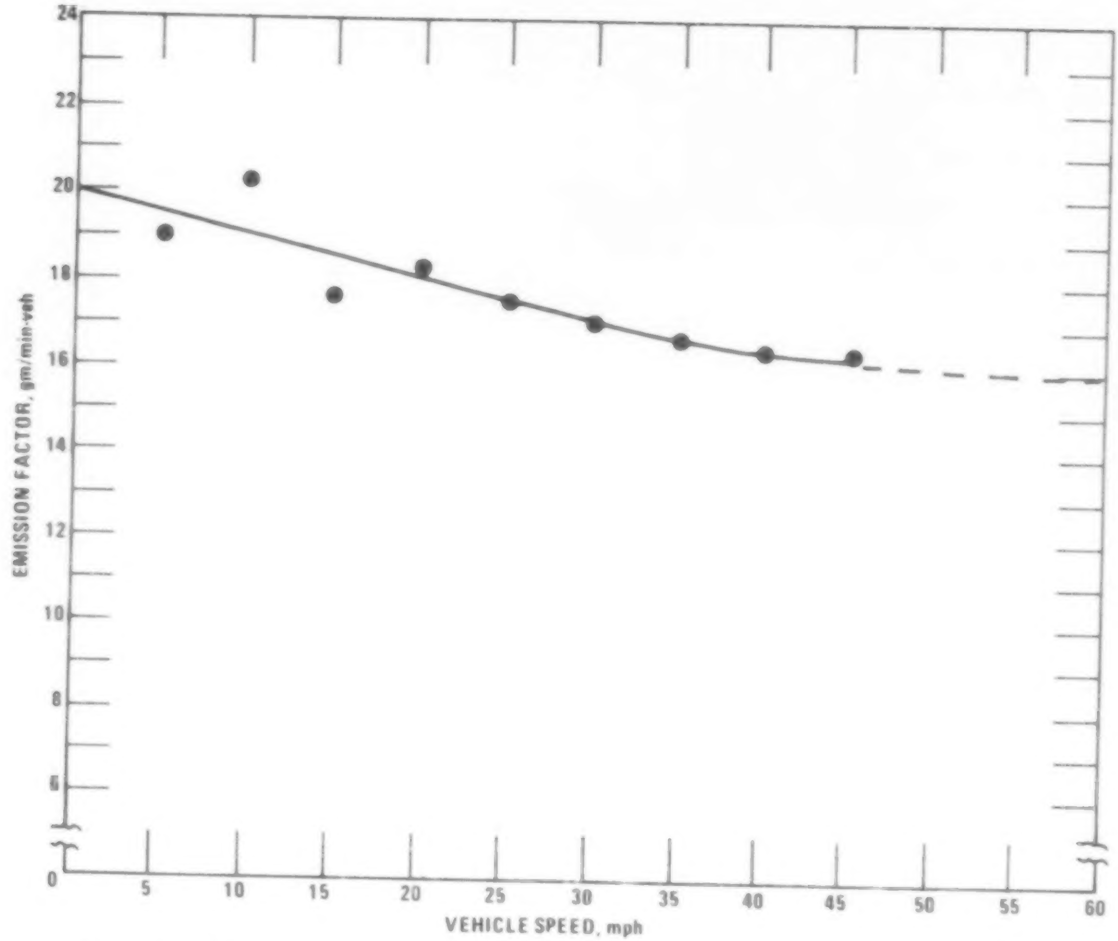


Figure E1. Composite emission factors for carbon monoxide for calendar year 1975.

1. Determination of Emission Factors

Probably the most accurate estimates of emission factors for vehicles at parking lots could be obtained if typical driving cycles (i.e. amounts of time and sequences spent in acceleration, deceleration and steady speed modes of travel) could be estimated for the parking lot. A typical driving cycle could then be simulated using the EPA Automobile Exhaust Emission Modal Analysis Model[2] to obtain average trip emission factors which were explicit for the parking lot. This approach has been followed in characterizing emissions at signalized intersections in Appendix A. If vehicle operating data are insufficient at parking lots to take this approach elsewhere in a parking lot, the CO emission factors which are based on the 1975 Federal Test Procedure (FTP)[4] may have to suffice. Figure E1 was derived using the 1975 FTP trip emission factor for CO presented in Table A3 of Appendix A for a 1975 mix of light-duty vehicles (consisting of 88 percent cars and 12 percent light trucks) and Tables 3.1.2-6a and b (Supplement 5[3]) to obtain appropriate speed correction factors [c(s)]. Note that emission factor corresponding to 0 mph is characteristic of stop-and-start traffic rather than idling. Emission factors for other years should be computed as shown in Eq. (E2).

$$EF = (\text{Value from Fig. E1}) [ef/55] \qquad (E2)$$

where

ef = the emission factor (gm/mi-veh) for the year of interest as indicated in Table A3, Appendix A.

55 = the emission factor for a 1975 mix of light-duty vehicles (88% cars, 12% light trucks), gm/mi-veh.

The emission factors previously derived are appropriate for national mixes of model years with a certain percentage (20%) of vehicles assumed to be operating from cold starts near sea level with ambient temperatures ranging from 68°-86°F. If local conditions are different from these assumptions, it may be necessary to multiply the emission factors obtained using the procedures outlined above by a local correction factor. If the assumptions concerning altitude, percentage of cold starts and ambient temperature used in deriving an emission factor are not appropriate, Section 4.4 of the screening procedure or Supplement 5 to AP-42 may be used to derive an appropriate correction factor.

It should be pointed out that if it is determined that extra emissions attributable to cold starts and cold temperatures only occur for a relatively short time (e.g., 4 minutes), higher emission factors should be used only until a typical vehicle becomes warm.

2. Determination of Traffic Volume Demand (V)

Parking facilities are distinctive from other types of indirect sources in that they do not provide a source of attraction per se. The traffic volume demand or use rate is dependent on two factors:

(1) The number of parking spaces (i.e. parking space capacity available in the facility), and

(2) The demographic and functional characteristics of the area served by the parking facility.

In the absence of indications to the contrary, it may be assumed that during periods of peak use, the parking facility is used to capacity. Hence, the peak number of vehicles running during any period of interest is directly proportional to the facility's parking space capacity. The rationale behind this assumption is that the parking facility is a business which is being run for the express (rather than incidental) purpose of accommodating vehicles. Given the costs of land and operating costs in most areas likely to be of interest, it seems reasonable to assume that a developer of a parking facility would make every effort not to design a facility which is never utilized to capacity. Conversely however, it would be a relatively easy matter to indicate when the facility is full and hence avoid the problem of having more vehicles than can be accommodated milling around looking for parking spaces.

The demographic-functional characteristics of the area surrounding the parking facility determines the diurnal pattern (and hence the peak 1-hour and 8-hour volume demands) of the parking facility use rate. For example, the peak one-hour volume demand for a facility serving primarily commuting traffic might represent a very high percentage of the facility's parking space capacity, while the use rate averaged over an 8-hour period might be considerably lower. On the other hand, a parking facility located in a downtown commercial district used primarily for shopping might have a fairly steady use rate in which the 1- and 8-hour peak use rates agreed closely. The percentage of the facility's parking capacity that these use rates represented would depend on the type of shopping done and the length of stay it engendered.

There are two procedures which might be used to estimate peak use rates for a proposed parking facility if the developer has not provided an estimate for these or if one wishes to check the estimate which is provided by the developer. The most preferable way would be to:

a. Observe use rates at a nearby facility serving the same or similar area.

b. Express these observed use rates as a function of the existing parking facility's parking space capacity as shown in Eq. (E4) or Eq. (E5) for 1- and 8-hour sampling times respectively.

$$v_u = \frac{\text{(peak use rate, veh/hr)}}{\text{(parking space capacity)}} \tag{E4}$$

$$v_u = \left[\frac{1/8 \sum_{t=1}^{8} \text{(use rate, veh/hr)}}{\text{(parking space capacity)}} \right]_{\substack{\text{peak contiguous} \\ \text{8-hr. period}}} \tag{E5}$$

v_u = relative use rate, hr^{-1}

c. Combine the estimates obtained with Eqs. (E4) or (E5) with the proposed facility's parking space capacity to estimate the peak 1-hour and/or 8-hour traffic volume demand in Eq. (E6).

$$V = v_u \text{ (parking space capacity)} \qquad \text{(E6)}$$

where

V = peak traffic volume demand, veh/hr.

If there are no existing parking facilities in the vicinity of the proposed one, or if data concerning diurnal use rate patterns are unavailable, an alternate technique for estimating peak 1-hour and 8-hour traffic volume demand would proceed as follows:

a. Obtain hourly traffic flow rates on roads nearby the proposed facility from the local highway department or from traffic counts.

b. Determine the total traffic flow on these roads during the operating hours of the proposed facility.

c. Use Eqs. (E7) or (E7a) to determine the peak 1- or 8-hour relative use (flow) rates, hr.$^{-1}$

$$v_u = \frac{\text{(Peak hourly traffic flow rate, veh/hr)}}{\Sigma\ \text{(hourly flow rates during the hours of the proposed facility's operation, veh)}} \qquad \text{(E7)}$$

$$v_u = \left[\frac{1/8 \sum_{t=1}^{8} \text{(Hourly traffic flow rate, veh/hr)}}{\Sigma\ \text{(hourly flow rates during hours of proposed facility's operation, veh)}}\right]_{\substack{\text{peak}\\ \text{contiguous}\\ \text{8-hour period}}} \qquad \text{(E7a)}$$

(d) Use Eq. (E6) to estimate peak 1-hour and/or 8-hour traffic volume demands.

The first technique for estimating peak 1- and 8-hour traffic flow rates is illustrated using example data contained in Fig. 8 of a report prepared for EPA on vehicle behavior in and around parking lots[1].

Table E2 presents the pertinent data on diurnal use rate patterns for the garage cited in the example. It is assumed that the parking space capacity for the facility illustrated in the following example is 700 vehicles.

Table E2. EXAMPLE DIURNAL USE RATE PATTERNS

Time of Day	Use Rate + (Veh/hr)	Relative Use Rate, (hr^{-1})	Running Average 8-hr. Relative Use Rate, (hr^{-1})
0800	17	.024	.003
0900	62	.089	.014
1000	147	.21	.040
1100	240	.34	.083
1200	242	.35	.13
1300	260	.37	.17
1400	297	.42*	.23
1500	266	.38	.27
1600	283	.40	.32
1700	223	.32	.35*
1800	131	.19	.35
1900	14	.02	.31

+ = use rate is assumed to be the sum of vehicle entrances and exits during the hour.

* = peak 1- and 8-hour relative use rates.

If a new garage with a parking space capacity of 500 spaces is planned nearby to serve the same type of clientele, then Eq. (6) may be used to estimate peak 1- and 8-hour traffic volume demands.

For 1 hour:

$$V = (.42)(500) = 210 \text{ vehicles/hr.} \qquad (E6)$$

For 8 hours:

$$V = (.35)(500) = 175 \text{ vehicles/hr.} \qquad (E6)$$

3. Determination of Average Vehicle Running Times (RT)

Traffic movement in a parking facility has been characterized by eight operational modes (approach, entrance, movement-in, stop, start, movement-out, exit, departure).[1] Associated with each parking facility, there is a characteristic vehicle running time which occurs when there is little or no congestion. This parameter is called the "Base Running Time," and it would be highly desirable for the developer to provide the control agency with an estimate of Base Running Time (BRT). Base Running Time may be estimated from a plan of the proposed facility indicating dimensions, parking space orientation, exit/entrance configurations, and from knowledge of traffic control devices, probable driving patterns and operational customs. An example of the procedure used in deriving base running time from the source's physical configuration and operating policies is illustrated by expressions (E8a)-(E8g).

$$\text{Base Approach Time} \sim \frac{\left(\begin{array}{l}\text{Distance between entrance and nearest}\\ \text{intersection on the access road, m}\end{array}\right)}{(\text{posted speed limit, m/sec})} \qquad \text{(E8a)}$$

$$\text{Base Entrance Time} \sim \frac{1}{(\text{Main entrance gate capacity, veh/sec})} \qquad \text{(E8b)}$$

$$\text{Base Movement-in Time} \sim \frac{\left(\begin{array}{l}\text{Distance from center of lot to main}\\ \text{entrance measured along traffic lanes, m}\end{array}\right)}{(\text{speed limit in lot, m/sec})} \qquad \text{(E8c)}$$

Base Stop, Base Start Time ~ 5-10 sec each depending on angle of parking lane width (E8d)

$$\text{Base Movement-out Time} \sim \frac{\left(\begin{array}{l}\text{Distance from center of lot to main exit}\\ \text{measured along traffic lanes, m}\end{array}\right)}{(\text{speed limit in lot, m/sec})} \qquad \text{(E8e)}$$

$$\text{Base Exit Time} \sim \frac{1}{(\text{main exit gate capacity, veh/sec})} \qquad \text{(E8f)}$$

$$\text{Base Departure Time} \sim \frac{\left(\begin{array}{l}\text{Distance between main exit and nearest}\\ \text{intersection on the access road, m}\end{array}\right)}{(\text{posted speed limit, m/sec})} \qquad \text{(E8g)}$$

BRT ~ (E8a) + (E8b) + (E8c) + (E8d) + (E8e) + (E8f) + (E8g)

Table E3 presents typical values for BRT observed for a limited number of parking garages.

Table E3. EXAMPLE BASE RUNNING TIMES FOR PARKING GARAGES

Type of Operation	Base Running Time, sec
Attendant-operated	200
Self-parking	250

The longer BRT's associated with self-parking are attributed to vehicles idling longer near exits and entrances while picking up the parking ticket or paying the bill.

In calculating emission density, it is critically important that running time be properly coordinated with traffic volume demand. For example, the peak volume demand (V) previously calculated includes vehicles both arriving and leaving. Hence a single vehicle is, in effect, counted twice--once when it arrives, once when it leaves. Therefore, if one were to use the total Base Running Time in conjunction with the previously derived peak volume demand, emissions would be overestimated. Since BRT's appear to be approximately evenly divided among arriving and departing modes,[1] it is recommended that one-half the BRT be used in computing running times for parking facilities.

a. Running Times at Self-Parking Facilities

For any period of interest, total running time for self-parking facilities may be expressed as the sum of the Base Running Time plus the average of any increased delay occurring as the result of congestion at exits/entrances.

$$RT = \frac{BRT}{2} + \overline{RT}_q \qquad (E9)$$

where RT and BRT are expressed in seconds, and $\overline{RT}_q$ is the average excess running time spent in exit and entrance queues, sec. The average excess running time spent in entrance/exit queues ($\overline{RT}_q$) depends on how the traffic volume demand is apportioned among exits and entrances during the peak 1-hour and 8-hour use periods, and upon the individual exit and entrance gate capacities. The excess running time spent in an exit queue at unsignalized exit gate j with an exit traffic volume demand of $X_j{}^7$ is given by Eq. (E10), (E11), or (E12).

$$RT_{qj} = \frac{3600}{C_j}\left[\frac{X_j}{C_j - X_j}\right], \quad X_j/C_j \leq .95 \qquad \text{(E10)}$$

$$RT_{qj} = 3600\left(\frac{20}{C_j}\right), \quad .95 > X_j/C_j \leq 1 \qquad \text{(E11)}$$

$$RT_{qj} = 3600\left[\frac{20}{C_j} + \frac{(X_j - C_j)}{2C_j}\right] \qquad \text{(E12)}$$

where

C_j = capacity of the exit to accommodate vehicles, veh/hr.

X_j = traffic demand using exit j, veh/hr.

3600 = conversion factor from hr. to sec.

Excess running time spent entering or exiting from a parking lot with signalized exit/entrances may be estimated using Equation (E12)[8].

$$\left(RT_q\right)_j = \frac{(C_y)\,(c')\,(1-G/C_y)^2}{2(c' - v)} + \frac{1800\ v\ C_y{}^2}{c'\ G(c'G - vC_y)}_j \qquad \text{(E13)}$$

where

$\left(RT_q\right)_j$ = excess running time spent entering or exiting at entrance/exit j, sec i

C_y = signal cycle length, sec.

c' = unimpeded capacity at a signalized intersection approach, vph

G = amount of green time per signal cycle for the intersection approach of interest, sec.

G/C_y = green time to signal cycle ratio, dimensionless.

v = traffic demand at the intersection approach of interest, vph.

Ideally, it would be desirable if the apportionment of traffic volume demand for various gates were provided by the developer as the result of traffic projections made in designing the facility. If such information is not available, one of two methods could be used to apportion traffic through various gates. The most preferable method would be to apportion gate use according to access road capacity. Thus for gate j

$$X_j = e_j V \left[\frac{\text{capacity of access road } j}{\Sigma\ (\text{capacity of all access roads})}\right] \qquad \text{(E14a)}$$

where

X_j = exit traffic flow through gate j, veh/hr.

e_j = fraction exit traffic is of the total traffic passing through gate j.

Conversely, the entering traffic passing through gate j can be estimated using Eq. (E14b).

$$M_j = (1-e_j)\ V \left[\frac{\text{capacity of access road } j}{\Sigma\ (\text{capacity of access roads})}\right] \qquad \text{(E14b)}$$

where

M_j = entrance traffic flow through gate j, veh/hr.

Equations (E10) - (E12) or (E13) may be used to estimate excess running time associated with entrance queues as well. If such a procedure is followed, each M_j is apportioned directionally on the access road, and the entering traffic from each direction is set equal to v_j. This v_j value is then substituted for X_j in Eqs. (E10) - (E12) or for v in Eq. (E13). The excess running time spent entering entrance j would be the mean value of the excess running time spent entering entrance j from each direction on the access road.

Since it is not very likely that incoming and outgoing traffic will be evenly divided during a peak use period, values for "e_j" in Equations (E14) are likely to be greater than "0.7" or less than "0.3." At parking lots serving event-oriented attractions (such as the theatre district), at the conclusion of the event the fraction of exiting traffic is likely to approach "1" while entering traffic would be insignificant. The fraction e_j should be determined by observing entrance and exit counts at nearby existing facilities and using Eq. (E15)

$$e_j = \frac{(\text{exits/hr})}{V_j} \tag{E15}$$

where

V_j = traffic volume demand using gate j (exits and entrances), veh/hr.

If it is not possible to obtain data for nearby existing facilities , an "e_j" value of 0.8 (or 0.2) should be used for facilities which will not be located near event-oriented attractions or attractions exhibiting a distinctively skewed diurnal use pattern (e.g. commuter lots). For all other facilities, "e_j" should be assumed to be 1.0 (or 0). If there are two or more gates onto the same access road or if traffic capacity data are unavailable for the access roads, traffic volume demand should be apportioned according to gate capacities. Thus,

$$X_j = e_j \left[V \frac{c_j}{\sum\limits_{V_j} c_j} \right] \qquad \text{(E16a)}$$

where c_j = exit gate capacity, veh/sec

$$\text{and } M_j = (1-e_j)\, V \left[\frac{G_j}{\sum\limits_{V_j} G_j} \right] \qquad \text{(E16b)}$$

where G_j = entrance gate capacity (obtained by averaging the capacity for right and left turns from the access road).

Thus,

$$\overline{RT}_q = \frac{\sum\limits_{\substack{\text{all entrance}\\ \text{and exit queues}}} \left(RT_{qj}\right)}{J} \qquad \text{(E16c)}$$

where J = number of exit gates + entrance gates*

b. Running Times at Attendant-Operated Facilities

It is very unlikely that total running time per trip will increase substantially over $\frac{BRT}{2}$ at attendant-operated lots. This is a result of people simply leaving their vehicles at the lot to be parked later by the attendant or waiting at the cashier window for the attendant to deliver their car. In neither case, is the vehicle likely to be found in a queue with its engine running. An exception to this may occur if the facility's reservoir capacity (i.e. the max. allowable backlog of cars which can be left within the facility without being parked) is exceeded by the peak arrival rate. In such a case some vehicles may be idling in queues waiting to get into the facility. Thus, for attendant-operated facilities, the reservoir capacity should be checked to insure that it would exceed the projected backlog of vehicles under the estimated peak arrival rate. This check can be performed using Eq. (E17) and Fig. E2.

---

*If one gate has exit and entrance lanes, it counts as 2 gates.

$$P = \frac{60\ N}{T} \qquad \text{(E17)}$$

where P = the parking storage rate, vehicles/hr.

N = the number of attendants on duty

T = the average time (minutes) required by an attendant to park a vehicle

Figure E2[9] depicts the reservoir capacity needed when the parking storage rate is less than or approaching the arrival rate. The peak arrival rate will always be less than the peak use rate (which counts both entering and leaving traffic). How much less is a function of the demographic and functional characteristics of the area in which the facility is to be located. The fraction the peak arrival rate is of the peak use rate $(1-e_j)$ can best be estimated by observing counts of entering and leaving traffic at nearby existing facilities similar to the manner in the preferred method for estimating diurnal usage patterns described earlier. If this is impractical, in the absence of indications to the contrary, peak arrival rate should be set equal to peak use rate for facilities located near event-oriented attractions or diurnally-skewed attractions. For all other facilities the arrival rate should be assumed to be 0.8 times the use rate. Unless the reservoir capacity is inadequate to accommodate the peak arrival rate [as determined by Eq. (E17) and Fig. E2], vehicle running times for attendant-operated lots should be assumed equal to the Base Running Time values divided by "2." In the rate cases when reservoir capacity is exceeded, running time per vehicle should be estimated using Eq. (E17a).

$$RT = \frac{BRT}{2} + 3600 \left[\frac{(\text{Peak Arrival Rate}) - P}{2P}\right] \qquad \text{(E17a)}$$

where P = parking storage rate, veh/hr.

"3600" = number of seconds in which storage rate is exceeded during an hour.

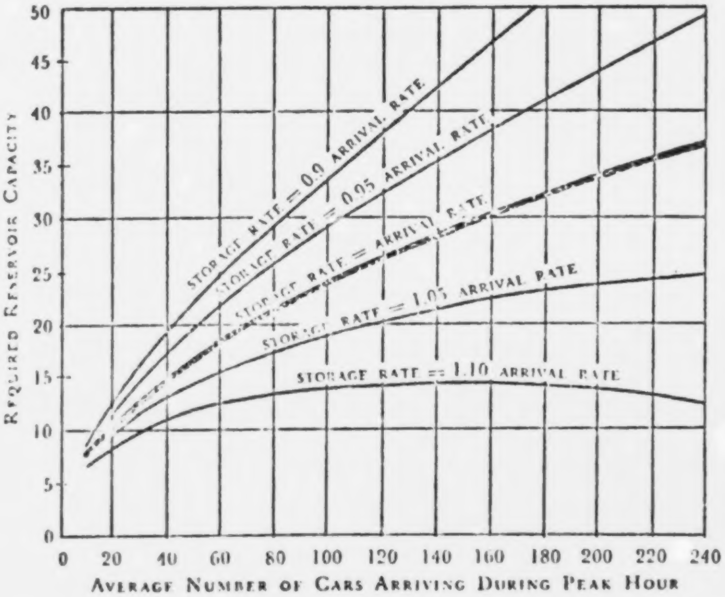


Figure E2. RESERVOIR SPACE

B. Estimating Peak Impacts Within or Near the Parking Lot or on Access Roads Removed from the Lot

Peak concentrations of CO are likely to occur in the vicinity of exit/entrances to the lot, near access roads or at nearby intersections. Traffic at such locations may be characterized as line sources of pollution. Two situations are of interest: the case where traffic flows freely by the receptor; and the case where queues form in the vicinity of the receptor. At traffic lanes within or adjacent to an open parking lot, the impact of freely flowing and/or queuing vehicles on CO concentrations in the vicinity of the lanes should be added to estimates obtained using an area source model relating the source's upwind dimension and emission density to CO concentrations and general background levels. More details concerning this procedure are presented in Appendix H. Equation (E1) is used to estimate the appropriate emission density.

$$Q = \frac{(EF)\ (V)\ (RT)}{216{,}000\ A} \qquad (E1)$$

The discussion in Appendix A concerning microscale impact analysis may be used to estimate the impact of freely flowing and/or queuing traffic on nearby CO concentrations. Equation (A11) is used to estimate the impact of freely flowing traffic. If traffic at a signalized intersection is of interest, excess emissions over a finite queue [obtained using Equations (A18) and (A19)] are added to emissions estimated for line sources of freely flowing traffic with Eq. (A11). Emissions near a non-signalized intersection may be approximated with Equations (A20)-(A23) and with Equation (A11).

REFERENCES

(1) Thayer, S. D., "Vehicle Behavior in and Around Complex Sources and Related Complex Source Characteristics: Volume IV - Parking Facilities;" EPA-450/3-74-003 d. (October 1973); National Technical Information Service, Springfield, Va. 22161.

(2) Kunselman, P., H. T. McAdams, C. J. Domke and M. Williams; "Automobile Exhaust Emission Modal Analysis Model;" EPA-460/3-74-005; (January 1974); National Technical Information Service, Springfield, Va. 22161.

(3) "Compilation of Air Pollutant Emission Factors," EPA Publication No. AP-42 (Second Edition) Supplement 5; (In Press).

(4) 40 CFR 85; "1975 Federal Test Procedures;" Federal Register 36, No. 128; (July 2, 1971).

(5) Williams, M. E., J. T. White, L. A. Platte, and C. J. Domke; "Automobile Exhause Emission Surveillance--Analysis of the FY 72 Program;" EPA-460/2-74-001; (February 1974); National Technical Information Service; Springfield, Va. 22161.

(6) Ashby, H. A., R. C. Stahman, B. H. Eccleston, and R. W. Hurn; "Vehicle Emissions--Summer to Winter;" Paper No. 741053 presented at the SAE Automobile Engineering Meeting; Toronto, Canada; (Oct. 21-25, 1974); Society of Automotive Engineers, Inc.; 400 Commonwealth Drive, Warrendale, Pa. 15096.

(7) Hillier, F. S. and G. J. Lieberman, Introduction to Operations Research, Holden-Day, Inc.; San Francisco, Calif.; (1967); Ch. 10.

(8) Newell, G. F.; "Approximate Methods for Queues with Application to the Fixed Cycle Traffic Light;" SIAM Review 7 No. 2; (1965).

(9) The Eno Foundation for Highway Traffic Control, "Parking," (1957); Saugatuck, Ct.

APPENDIX F. METHOD FOR ESTIMATING EMISSIONS AT AMUSEMENT PARKS

This appendix is intended to provide guidance concerning a more detailed analysis of proposed indirect sources should this be necessary or desirable pursuant to 40 CFR 52.22(b). The materials contained herein are offered as suggestions. Alternate analytical approaches for evaluating the impact of a proposed source may be used if it can be demonstrated that they are more applicable to the source under review.

U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, N.C. 27711

January 1975

APPENDIX F.

METHOD FOR ESTIMATING EMISSIONS AT AMUSEMENT PARKS

The purpose of this appendix is to provide a means for assisting air pollution control agencies or developers to estimate vehicular emissions associated with the operation of an amusement park. Generally, there are two types of amusement parks in operation--the "theme" type (e.g., Disneyland) with shows and exhibits, and the "traditional" type with rides and games only (e.g., Coney Island)[1]. Since the "theme" park represents a substantial development which is a relatively rare event, a more complete environmental impact analysis would appear warranted. The analysis herein has the more limited objective of estimating emissions using design and operating parameters known to the developer. The estimated emissions will subsequently be used to estimate the impact of the amusement park on ambient air quality in the immediate vicinity of the park.

Section FI of this appendix summarizes a methodology which could be used to estimate total CO emissions arising from the operation of an amusement park, and to estimate CO emissions in the vicinity of locations likely to experience peak CO concentrations (e.g., exit/entrance gates, traffic lanes, nearby intersection approaches). The remaining portions of the appendix discuss how the methodology described in Section FI might best be implemented.

FI. Procedure for Estimating Emissions in the Vicinity of an Amusement Park

1. Obtain estimates for the design and operating parameters included in Table F1.

2. Estimate emission factors (EF) for vehicles utilizing the amusement park based on the appropriate driving cycle for vehicles utilizing amusement parks. If this is not practical use Fig. F1 (and Eq. (F2), if necessary) to estimate the appropriate emission factor for automobiles. For buses, use Sections 3.1.4.3 and 3.1.5 to estimate emission factors for gasoline and diesel-powered vehicles. Use Eq. (F3) to estimate a composite emission factor for buses. If appropriate local data concerning the nature of operation and the mix of local vehicles are available, multiply the emission factor by a local correction factor. Use guidance in Section 4.4 of the screening procedure or Supplement 5 to AP-42 to derive correction factors for differing percentages of cold starting vehicles, ambient temperatures and altitudes.

3. Use Eqs. (F6) and (F7) so that Eq. (F5) may be used to estimate the traffic volume demand (V) at the amusement park during the period of interest.

4. Estimate Base Running Time (BRT) using expressions similar to (F8a)-(F8g) and Eq. (F9).

5. During periods in which the main parking lot(s) are full, extra running time required to move to auxiliary overflow lots should be estimated using Eq. (F10).

6. Apportion exiting and entering traffic among exit and entrance gates using Eqs. (F12) and (F13), or (F14) and (F15). If the information required to use (F12)-(F15) is not available, use Eqs. (F17) and (F18) or (F19) and (F20).

7. Use Eq. (F10) or Eq. (F20) or Eq. (F21) to estimate the excess running time spent in queues at each exit and entrance gate not having a traffic signal. Use Eq. (F23) to estimate excess running time at signalized entrance/exits. Use Eq. (F24) to estimate average excess running time spent in queues.

8. Estimate running time (RT) in Eq. (F25) using the information obtained from Eqs. (F9), (F10) and (F24).

9. Estimate emission density in the amusement park's traffic lots using Eq. (F1).

10. Refer to the microanalysis section in Appendix A to estimate the impact of freely flowing and/or queueing traffic on nearby CO concentrations. The procedure is as follows:

a. Estimate traffic demand for each lane j in road segment i using Eqs. (A12) or (A13). If necessary, adjust the demand for the impact of mass transit using Eqs. (A14) or (A15). Apportion demand among lanes, making sure that Eq. (A2) is satisfied.

b. If the analysis does not concern an at-grade intersection, estimate capacity of the road segment using Eq. (A10) and the lane capacities using Eq. (A16). Check that Eq. (A3) is satisfied. If not, adjust the lane capacities so that Eq. (A3) is satisfied.

c. Determine volume to capacity ratios (v_{ij}/c_{ij}) for each lane. Given the type of road and the average highway speed, use the appropriate one of Figs. A2-A5 to estimate vehicle operating speeds in each lane.

d. Use Fig. A6 to estimate the speed corrected 1975 emission factor for each lane. For years other than 1975, adjust this factor with Equation (A17). Use Section 4.4 of the screening procedure or Supplement 5 of AP-42 to correct for cold starts and ambient temperature, as needed.

e. Use Eq. (A11) to estimate the line source emission intensity of freely flowing traffic.

f. For at-grade signalized intersections, use information concerning signal cycle lengths and green time to signal cycle ratios to estimate queue lengths with Eq. (A18). Consider emissions over the queue length to be the sum of those from freely flowing traffic and excess emissions. Elsewhere, emissions are attributable to freely flowing traffic. Estimate emissions from freely flowing traffic using Eq. (A11), and excess emissions using Eq. (A19). Alternatively, use the information in Tables A8-A12 directly to estimate appropriate emissions and queue lengths.

g. For non-signalized intersections, estimate the average queue length using Eq. (A20). Use Eq. (A21) to estimate the emission intensity over the queue at the intersection approach. Estimate the distances over which vehicles may accelerate and decelerate using Eq. (A22). The emission intensity over this distance is obtained using Eq. (A23). Use Eq. (A11) to estimate emission intensity elsewhere.

FII. Identification of Key Design and Operating Variables

Two key elements in the design of an amusement park become evident in assessing the park's impact on emissions[1]:

(1) The entrance capacity must be sufficient to handle park arrival rates without creating long entrance queues, and

(2) The number of parking spaces must be sufficient to accommodate the peak accumulation of vehicles in the lots or an efficient operational means should be used to route excess traffic to overflow parking areas.

The approach taken in this appendix is to identify certain essential amusement park design and operating parameters which must be supplied by the prospective developer. A second body of information is specified as highly desirable, and should be provided by the developer if possible. If it is not possible for the developer to provide the optional information, the appropriate parameters are estimated using information compiled for a number of existing amusement parks[1] or by making best judgment estimates given the parameters which the developer may supply. The essential and desirable parameters are then used to estimate peak traffic volume demand and accompanying running times for typical vehicles. This information, when combined with information concerning emission factors, enables estimates of vehicular emissions to be made.

Table F1 presents the essential and highly desirable parameters which should be provided by developers. Referring to Table F1, "peak capacity" would be synonymous with <ins>peak</ins> total daily attendance. Anticipated diurnal arrival and departure patterns are critical in determining the number of vehicles running in a park's lots during the peak 1- and 8-hour use periods. Available parking spaces and gate capacities are extremely important in determining how congested a lot is likely to become with peak use rates. Percent of crowd likely to arrive by automobile and number of buses likely to be present are important parameters in that they enable better estimates of peak traffic volume demand to be made, given crowd projections. Average vehicle occupancy is a highly desirable parameter because it provides a means for estimating traffic volume from crowd projections. Ratio of people in the park to total daily admission ticket sales is also desirable because it facilitates an estimate of peak occupancy in the parking lot. Base Running Time is of importance because it is needed to estimate typical emission levels with little congestion, while the excess time required to move to auxiliary lots may be of interest during periods of peak use. Distribution of traffic demand among exit/entrance gates and access roads is essential to know in order to determine whether congestion is likely to occur at these key locations.

TABLE F1. AMUSEMENT PARK PARAMETERS NEEDED FOR AIR QUALITY IMPACT ANALYSIS

I. Essential Parameters

Parameter	Remarks
Peak Capacity	Maximum number of visitors that can be accommodated with the existing park configuration
Anticipated Diurnal Arrival and Departure Patterns	Fraction that entering and leaving vehicles comprise of the total daily arrivals during each hour of the park's operation on days with anticipated capacity crowds
Available Visitor and Employee Parking Spaces	
Physical Layout and Dimensions of the Amusement Park	Needed to help estimate running times and identify locations with heaviest congestion
Number of Employees and Percent of Employees Arriving by Automobile	
Number of Buses Expected and Fraction of Visitors Using Mass Transit	
Gate Capacities	Number of vehicles which can be accommodated through each entrance (exit) per unit time
Traffic Volume Demand and Capacities for Access Roads and at Intersection Approaches	Needed to determine the impact of the park at nearby approaches
Green Time to Signal Cycle Ratio at Nearby Intersection Approaches	Needed to estimate intersection approach capacities and queue lengths on approaches during the red phase
Number of Signal Cycles Per Hour at Each Nearby Intersection	Needed to estimate queue lengths on each intersection during the red phase for each approach

Table F1 (Continued). AMUSEMENT PARK PARAMETERS NEEDED FOR AIR QUALITY IMPACT ANALYSIS

II. Highly Desirable Parameters

Parameter	Remarks
Base Running Time (BRT)	Total time a typical vehicle is likely to spend with the engine on while arriving and leaving the park during periods with little or no congestion
Average Vehicle Occupancy	The average number of visitors expected per vehicle during periods with capacity crowds
Estimated Ratio of People in the Park at the Most Crowded Time of Day to Total Daily Admission Ticket Sales	
Estimated Time Required for Vehicles to Move to Auxiliary Lots when the Parking Capacity in the Main Lot is Exceeded	
Distribution of Vehicles through Exit/Entrance Gates	

FIII. Estimating Emissions in the Vicinity of an Amusement Park

Two types of analyses are necessary in estimating vehicular emissions likely to occur as a result of the operation of a proposed amusement park. First, CO emission density attributable to vehicles utilizing the source and significant stationary source emissions should be estimated. Second, emission rates in the immediate vicinity of locations which are most likely to become congested (e.g. traffic lanes leading to exit/entrances and intersection approaches) should be estimated.

A. Emission Density

Estimates of total emissions and emission density are important because they:

(1) Provide means for relating the operation of the amusement park to emission density limitations which may be proposed as a part of land use plans or air quality maintenance plans, and

(2) Provide means for estimating the impact of the amusement park on representative concentrations of CO at the site of the amusement park.

Equation (F1) may be used to estimate emission density at the amusement park's parking lots:

$$Q = \frac{[(EF)(V)(RT)]_{autos} + [(EF)(B)(RT)]_{buses}}{216{,}000\ A} \qquad (F1)$$

where EF = emission factor, gm/min-veh

V = auto traffic volume demand, veh/hr

B = bus traffic volume demand, veh/hr

RT = running time spent in a typical trip* in the lot, sec

A = area occupied by the parking lots, m^2

Q = emission density, gm/sec-m^2

1/216,000 = conversion factor from $\frac{\text{gm-sec}}{\text{min-hr}}$ to gm/sec.

Specific account of emissions from buses may be desirable in Eq. (F1), because the emission factors for buses could be appreciably different from those for autos. In addition, if separate parking facilities are provided for buses, the running time for buses may be quite different than that for autos. Finally, an explicit term for buses would facilitate analysis of the effect that providing increased mass transit would have on emissions.

1. Estimating Emission Factors

(a) Automobiles

Probably the most accurate estimates of CO emission factors at amusement parks could be obtained if typical driving cycles (i.e. sequence and amounts of time spent in acceleration, deceleration and steady speed modes of travel) could be estimated explicitly for amusement parks. Such a driving cycle could then be simulated with EPA's Automobile Exhaust Emission Modal Analysis Model[2] to obtain average trip emission factors for amusement parks. This approach has been followed in characterizing emissions at signalized intersections in Appendix A. Unfortunately, the data to implement such a technique elsewhere within an amusement park are not available. Consequently, use of CO emission factors based on the 1975 Federal Test Procedure (FTP)[4] may have to suffice. Figure F1 was obtained using the FTP emission factor for CO presented in Table A3 of Appendix A for a 1975 mix of light-duty vehicles (88 percent cars, 12 percent light trucks) and Tables 3.1.2-6a and b in Supplement 5 of AP-42 to obtain appropriate speed correction factors (c(s)). Equation (F2) should be used to estimate emission factors for vehicle mixes of automobiles during years other than 1975.

---

*1 trip is a one-way visit to the park. A typical vehicle makes 2 trips--one coming, one going.

$$EF = \left[\begin{array}{c}\text{emission factor} \\ \text{obtained from Fig. F1}\end{array}\right]\left(\frac{ef}{55}\right) \qquad \text{(F2)}$$

where ef = CO emission factor obtained from Table A3 for the year of interest, gm/mi-veh

"55" = CO emission factor for 1975 obtained from Table A3, gm/mi-veh

(b) Buses

Sections 3.1.4.3 and 3.1.5 in Supplement 5 to AP-42[3] provide emission factors (gm/mi-veh) for heavy-duty gasoline and diesel-powered vehicles respectively. Once the appropriate emission factor for gasoline and diesel-powered buses is estimated from AP-42, a bus CO emission factor with units suitable for use in Eq. (F1) can be calculated using Eq. (F3).

$$EF = \left[\frac{\text{emission factor obtained from Fig. F1}}{(ef)}\right]\frac{\left(\begin{array}{c}\text{\# gas.} \\ \text{powered} \\ \text{buses}\end{array}\right)(ef)_g + \left(\begin{array}{c}\text{\#diesel-} \\ \text{powered} \\ \text{buses}\end{array}\right)(ef)_d}{(\text{total \# of buses})} \qquad \text{(F3)}$$

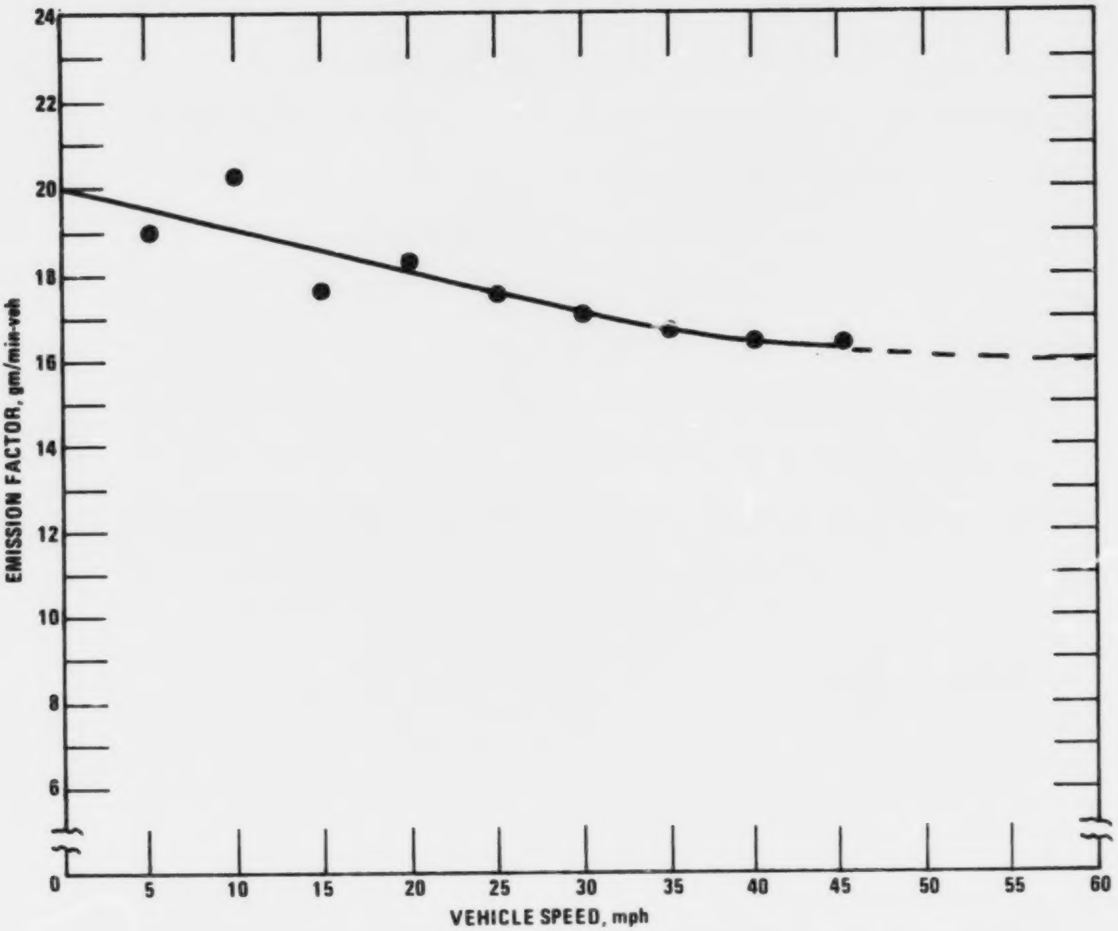


Figure F1. Composite emission factors for carbon monoxide for calendar year 1975.

where $(ef)_g$ = the estimated emission factor for heavy-duty gasoline-powered vehicles as determined from Section 3.1.4.3 in Supplement 5 to AP-42, gm/mi-veh,

$(ef)_d$ = the estimated emission factor for heavy duty diesel powered vehicles as determined from Section 3.1.5 in Supplement 5 to AP-42, gm/mi-veh,

(ef) = emission factor for light-duty vehicles (gm/mi-veh) estimated from Table A3 or from Supplement 5 to AP-42.

The use of Figure F1 and Equations (F2) and (F3) implies a number of assumptions about the mix of vehicles, percentage of cold starts, altitude factors, ambient temperature, etc. These assumptions are documented in Appendix A. If local data are available which indicate these assumptions are not applicable, the emission factor obtained should be multiplied by a local correction factor. If the assumptions concerning altitude, percentage of cold starts and ambient temperature used in deriving an emission factor are not appropriate, guidance in Section 4.4 of the screening procedure or Supplement 5 to AP-42 may be used to derive a correction factor to the estimates. It should be pointed out that if it is determined that extra emissions attributable to cold starts and cold temperatures only occur for a relatively short time (e.g., 4 minutes), higher emission factors should be used only until a typical vehicle becomes warm.

2. Estimating Traffic Volume Demand (V)

For any number of hours t, the traffic volume demand can be estimated using Eq. (F5).

$$V = \left[\frac{(P)(d_t)(G)}{(avo)} + d_t' B + \frac{(F_t)(E)(PE)}{(avo)_e} \right] \qquad (F5)$$

where P = fraction of the crowd arriving by automobile

d_t = fraction that entering and leaving vehicles comprise during time period "t" of the total daily vehicle arrivals

G = estimated peak total daily admission tickets sold (i.e. equal to peak capacity parameter in Table F1)

avo = average automobile occupancy for visitors

$(avo)_e$ = average vehicle occupancy, employees

B = number of buses arriving and leaving during the period of interest

F_t = average hourly fraction of employees arriving and leaving during time period t, estimated from diurnal arrival-departure patterns for employees

V = traffic volume demand, vph

E = number of park employees

PE = fraction of employees arriving by auto

Estimates of the parameters "G," "B," "E," "P," and "PE" must be supplied by the developer and would be used directly in Eq. (F5). The parameters "d_t" and "F_t" are derivable from the estimates of diurnal arrival and departure patterns required from the developer, as shown by Eqs. (F6) and (F7).

$$d_t = \frac{(\text{\# of arrivals + \# of departures})_t}{(\text{\# of arrivals on the peak day})(t)} \qquad \text{(F6a)}$$

or

$$d_t = \frac{\begin{pmatrix}\text{fraction of total}\\ \text{daily arrivals}\end{pmatrix}_t + \begin{pmatrix}\text{fraction of total}\\ \text{daily departures}\end{pmatrix}_t}{t} \qquad \text{(F6b)}$$

where t is the number of hours in time period t, hr.

Unless there are explicit indications to the contrary, d'_t should be assumed equal to d_t.

$$F_t = \frac{(\text{\# of employee arrivals + \# of employee departures})_t}{(\text{\# of employees})(t)} \quad \text{(F7)}$$

Average visitor vehicle occupancy (avo) is a highly desirable parameter for the developer to provide. However, if this is not possible, past observations[1] have indicated a range of about 3.2-4.0 persons/vehicle with a mean of 3.6. Therefore, in the absence of better information, a value of "3.6" should be assumed for avo. Unless there are indications to the contrary, the average vehicle occupancy for employees $(avo)_e$ may be assumed as "1.3."

For consistency, the diurnal arrival and departure patterns provided by the developer should be checked against the ratio of people in the park at the most crowded time to total daily admission ticket sales (R). While the anticipated diurnal arrival and departure patterns are required information, it is recognized that they may be somewhat difficult to estimate. The information in Table F2 is based on observations at existing amusement parks[1], and is provided as a guide. As a last resort, in the absence of better information the values for "d_t" in Table F2 may be used.

Table F2. DIURNAL USE PATTERN PARAMETERS OBSERVED FOR EXISTING AMUSEMENT PARKS

Time Period, t	d_t	R
1 hour	.25	.85
8 hours	.15	.73

3. Estimating Average Trip Running Time (RT)

Eight vehicular operational modes have been identified as contributing to total vehicle running time[1]. These are:

(a) Approach Mode--Time vehicle spends running on access roads (usually on park property) during which traffic movement is strongly affected by vehicles entering or leaving the park;

(b) Entrance Mode--Waiting and service time at the ticket gate or entranceway to the parking lot;

(c) Movement In Mode--Driving time to the designated parking space;

(d) Stop Mode--Parking time;

(e) Start Mode--Time required for egress from parking space;

(f) Movement Out Mode--Driving time from parking space to preferred exit;

(g) Exit Mode--Time required to move through exitway;

(h) Departure Mode--Driving time along immediate access road during which movement continues to be influenced by traffic from the amusement park.

The total running time for a typical vehicle is the sum of the time spent in the 8 modes during periods with little congestion, plus any extra time resulting from congestion of the facility during peak usage periods. The time required during periods of little congestion is referred to as the Base Running Time (BRT) and ideally should be provided by the developer. If this estimate is not available, it can be obtained by studying the facility's physical configuration and proposed operating procedures. An example of the method used in estimating BRT is depicted by the following expressions:

$$\text{Base Approach Time} \sim \frac{\left(\begin{array}{l}\text{Distance between entrance and nearest}\\ \text{intersection on the access road, m}\end{array}\right)}{(\text{posted speed limit, m/sec})} \qquad \text{(F8a)}$$

$$\text{Base Entrance Time} \sim \frac{1}{(\text{main entrance gate capacity, veh/sec})} \qquad \text{(F8b)}$$

$$\text{Base Movement-In Time} \sim \frac{\left(\begin{array}{l}\text{Distance from center of lot}\\ \text{to main entrance measured}\\ \text{along traffic lanes, m}\end{array}\right)}{(\text{speed limit in lot, m/sec})} \qquad \text{(F8c)}$$

$$\text{Base Stop, Base Start Time} \sim \begin{array}{l}\text{5-10 sec each depended on angle}\\ \text{of parking and lane width}\end{array} \qquad \text{(F8d)}$$

$$\text{Base Movement-Out Time} \sim \frac{\left(\begin{array}{l}\text{Distance from center of lot to main}\\ \text{exit measured along traffic lanes}\end{array}\right)}{(\text{speed limit in lot, m/sec})} \qquad \text{(F8f)}$$

$$\text{Base Exit Time} \sim \frac{1}{(\text{main exit gate capacity, veh/sec})} \qquad \text{(F8f)}$$

$$\text{Base Departure Time} \sim \frac{\left(\begin{array}{l}\text{Distance between main exit and nearest}\\ \text{intersection on the access road, m}\end{array}\right)}{(\text{posted speed limit, m/sec})} \qquad \text{(F8g)}$$

$$\text{BRT} \sim \text{(F8a)} + \text{(F8b)} + \text{(F8c)} + \text{(F8d)} + \text{(F8e)} + \text{(F8f)} + \text{(F8g)} \qquad \text{(F9)}$$

Since both entering and leaving traffic are counted in estimating peak traffic volume demand, use of the total BRT to estimate running time would result in an inappropriately high estimate. In most cases the value which can be used would simply be BRT/2. This assumes that, with little or no congestion, running time is about equally divided between entering modes (modes a-d) and leaving modes (modes e-h). If the developer's estimates for base running times in each mode indicate that this simplifying assumption is inappropriate, it would be necessary to perform separate emission calculations for entering and leaving traffic. This analysis would be performed similarly to the methods described in this appendix, except that only that portion of the peak volume demand which was due to entering traffic would be associated with running times in modes (a-d) and only that portion of peak volume demand flow rate attributable to leaving traffic would be associated with running times in modes (e-h).

Running times for 3 of the 8 operating modes may be appreciably affected by congestion. The three modes are: the movement-in, entrance and exit modes. Time spent in the movement-in mode is increased if the main lot is full and the arriving visitors are forced to drive to an auxiliary parking area. This extra movement-in time, Δ_{MI}, is one of the "desirable parameters" called for in Table F1. If it is unavailable from the developer, it should be estimated using the physical plan and dimensions of the park's area provided by the developer. Unless the physical plan makes it inappropriate, Eq. (F10) could be used as a guidepost for estimating Δ_{MI}.

$$\Delta_{MI} = \frac{\left(\begin{array}{l}\text{Dist. from center of main}\\ \text{lot to main lot exit}\\ \text{along traffic lanes, m}\end{array}\right)}{\left(\begin{array}{l}\text{posted main lot speed}\\ \text{limit, m/sec}\end{array}\right)} + \frac{\left(\begin{array}{l}\text{Dist. between main lot exit}\\ \text{and aux. lot entrance, m}\end{array}\right)}{(\text{posted speed limit, m/sec})}$$

$$+ \frac{\left(\begin{array}{l}\text{Dist. between auxiliary lot}\\ \text{entrance and center of the}\\ \text{lot measured along traffic}\\ \text{lanes, m}\end{array}\right)}{(\text{posted aux. lot speed limit, m/sec})} \qquad \text{(F10)}$$

where Δ_{MI} is in seconds.

If the main parking lot is not full, Δ_{MI} is assumed to be zero. Whether or not the main lot is full, can be determined by examining the diurnal arrival-departure patterns provided by the developer, the resulting peak traffic demands on a peak day and the number of parking spaces in the main lot.

Increased running times also occur when the exiting traffic volume demand approaches exit gate capacity and/or entering traffic volume demand approaches entering gate capacities. When this happens queues form at the exit (entrance) thereby increasing running times. The increase in running time for each lane of traffic at gate i can usually be obtained for nonsignalized intersections or tollbooths from queuing theory using Equation (F11)[7]*.

$$RT_{qi} = \frac{3600}{c_i} \left(\frac{v_i}{c_i - v_i}\right), \quad v_i/c_i \leq .95 \qquad \text{(F11)}$$

---

*Separate analysis should be performed for entering and exiting traffic.

where RT_{qi} = time spent in the exit or entrance queue at gate i, sec

c_i = capacity of gate i (obtained from developer) veh/hr

v_i = traffic volume demand at gate i, veh/hr

The parameter "v_i" is obtained by apportioning the entering or exiting traffic volume demand among entering or exit gates. Ideally, the apportionment of entering and exiting traffic should be provided by the developer, and should be based on the orientation of the amusement park with respect to population centers. Entering traffic should be apportioned directionally on the access road, and the traffic in each direction should be set equal to "v_i." The excess running time spent entering entrance i would be the mean value of the excess time spent in each direction on the access road. If the apportionment is not provided, two procedures are suggested.

(a) Apportion exiting and entering traffic according to access road capacities.

$$E_i = [E] \left[\frac{\text{(Capacity of access road to gate i)}}{\text{(capacity of all access roads)}}\right] \qquad \text{(F12)}$$

where E_i = traffic entering demand at gate i during the one or eight hour period of interest, veh/hr.

E = total entering traffic demand during the one or eight hour period of interest, veh/hr.

and

$$X_i = [X] \left[\frac{\text{(Capacity of access road to gate i)}}{\text{(capacity of all access roads)}}\right] \qquad \text{(F13)}$$

where X_i = traffic exit demand from gate i during the 1- or 8-hour period of interest, veh/hr.

X = total traffic exit demand during the 1- or 8-hour period of interest, veh/hr.

(b) If access road capacities are unknown, or if more than one gate empties onto the same access road, traffic can be apportioned according to gate capacities.

$$E_i = [E]\left[\frac{\text{(Entrance capacity of gate i)}}{\text{(entrance capacity of all gates)}}\right] \qquad \text{(F14)}$$

and

$$X_i = [X]\left[\frac{\text{(Exit capacity of gate i)}}{\text{(exit capacity of all gates)}}\right] \qquad \text{(F15)}$$

It should be noted that for any period of interest, the traffic volume demand (V) is:

$$V = X + E \qquad \text{(F16)}$$

and at any gate i,

$$V_i = X_i + E_i \qquad \text{(F16a)}$$

If it is not possible to estimate exiting and entering traffic directly, estimates may be obtained from a limited data base compiled for EPA[1]. In examining diurnal arrival and departure rates for existing amusement parks comprising the EPA data base, it has been noted that the peak hourly demand (as determined by arrivals and departures) always occurs during periods in which traffic flow is either totally dominated by arrivals or by departures. Similarly, for 8-hour periods in which peak average hourly demand generated by visitors was observed, one mode outnumbered the other by a ratio of about 3:1. On the basis of these observations, for one hour periods in which peak demand occurs, all visitor traffic is assumed to be either exiting or entering. Similarly, for an 8-hour sampling period in which peak traffic volume demand occurs, it is assumed that 75% of the demand generated by visitors is trying to exit or enter. Thus, in the case of parks with more than one exit/entrance for peak 1-hour periods, the total peak traffic volume demand must be apportioned among the exit (or entrance) gates. For 8-hour sampling periods, 75% of the average hourly demand (over the 8-hour period) should be apportioned among the entrances (exits), and the remaining 25% among the exits (or entrances). The use of these assumptions is illustrated for 1- and 8-hour sampling periods in Eqs. (F17)-(F20), where V_i is the volume demand through gate i in veh/hr.

For 1-hour peaks:

$$V_i = \left[V - \frac{(F_t)(E)}{3600(avo)_e} \right] \cdot \left[\frac{\text{(Capacity of access road i)}}{\text{(capacity of all access roads)}} \right] \quad \text{(F17)}$$

For 8-hour peaks:

$$V_i = .75 \left[\bar{V}_8 - \frac{(F_t)(E)}{3600(avo)_e} \right] \cdot \left[\frac{\text{(Capacity of access road i)}}{\text{(capacity of all access roads)}} \right] \quad \text{(F1}$$

or

For 1-hour peaks:

$$V_i = \left[V - \frac{(F_t)(E)}{3600(avo)_e} \right] \left[\frac{\text{(Capacity of gate i)}}{\text{(capacity of all gates)}} \right] \quad \text{(F19)}$$

For 8-hour peaks:

$$V_i = .75 \left[\bar{V}_8 - \frac{(F_t)(E)}{3600(avo)_e} \right] \left[\frac{\text{(Capacity of gate i)}}{\text{(capacity of all gates)}} \right] \quad \text{(F20)}$$

where $\bar{V}_8$ is the average hourly traffic volume demand during the 8-hour period of interest, veh/hr. The other terms in Eqs. (F17)-(F20) are as defined for Eq. (F5).

Equations (F17) - (F20) assume employees park in a separate lot which does not become congested during periods of peak use. If separate lots are not provided, then the term in the left-hand square brackets in Eqs. (F17) - (F20) would simply be "V" or "$\overline{V}_8$." If the entering or exiting traffic at a nonsignalized gate is estimated to be greater than 95% of the gate's entering or exit capacity, the excess running time spent in queues should be estimated using Equation (F21) or Equation (F22).

$$RT_{qi} = 3600(20/c_i), \quad .95 < v_i/c_i \leq 1 \qquad \text{(F21)}$$

If $v_i/c_i > 1$,

$$RT_{qi} = 3600 \left[20/c_i + \frac{[v_i - c_i]}{2\ c_i} \right], \quad v_i/c_i > 1 \qquad \text{(F22)}$$

where "3600" is the number of seconds in the one-hour period in which the demand exceeds the capacity, and the other terms are as defined for Equation (F11).

Excess running time spend entering or exiting from a parking lot with signalized exit/entrances may be estimated using Equation (F23)[8] rather than (F11) or (F21).

$$RT_{q_i} = \left[\frac{(C_y)\ (c')\ (1-G/C_y)^2}{2\ (c' - v)} + \frac{1800\ vC_y^{\ 2}}{c'G\ (c'G - vC_y)} \right]_i \qquad \text{(F23)}$$

where

RT_{q_i} = excess running time spent entering or exiting at entrance/exit i, sec

C_y = signal cycle length, sec

c' = unimpeded capacity at a signalized intersection approach, veh/hr

G = amount of green time per signal cycle for the intersection approach of interest; sec

G/C_y = green time to signal cycle ratios, dimensionless

v = traffic demand at the intersection approach of interest, veh/hr.

If $v = c'$, use Equation (F22) instead.

Equation (F22) assumes that the hour of interest is the first in which demand exceeds capacity at gate i. If this were not the case, it would be necessary to go back to the first hour in which the entrance (or exit) demand (v_i) at gate i exceeded gate i's entrance (or exit) capacity and compute the queue buildup during each succeeding hour until the period of interest, t, is reached. For example, if demand first exceeded capacity 2 hours prior to the period of interest, average excess running time would be estimated by Eq. (F22a).

$$RT_{qi} = 3600 \left[20/c_i + \frac{[(v_i-c_i)_{t-2} + (v_i-c_i)_{t-1} + (v_i-c_i)_t]}{2\ c_i} \right] \tag{F22a}$$

The average excess running time spent by vehicles in entrance and exit queues at the amusement park is estimated by Eq. (F24)

$$\overline{RT}_q = \frac{\sum\limits_{\text{all } i} RT_{qi}}{I} \tag{F24}$$

where I = the total number of exit and entrance gates.

Equation (F25) can now be used to estimate average running time spent by a vehicle on 1 trip to or from the amusement park.

$$RT = \frac{BRT}{2} + \Delta_{MI} \left(\frac{\text{entering traffic}}{\text{total traffic}}\right) + \overline{RT}_q \tag{F25}$$

The BRT is divided by "2," because each trip is a one-way trip. Thus, in determining average daily trip generation rate (from which volume demand is derived), each vehicle is counted twice. Since the BRT refers to the total time required to enter and leave an amusement park, it should be divided by "2."

B. Estimating Peak Impacts Within or Near the Parking Lot or on Access Roads Removed from the Lot

Peak concentrations of CO are likely to occur in the vicinity of exit/entrances to the parking lot, near access roads or at nearby intersections. Traffic at such locations may be characterized as line sources of pollution. Two situations are of interest: the case when traffic flows freely by the receptor; and the case where queues form in the vicinity of the receptor. At traffic lanes within or adjacent to the parking lot, the impact of freely flowing and/or queuing vehicles on CO concentrations in the vicinity of the lanes should be added to estimates obtained using an area source model relating the source's upwind dimension and emission density to CO concentrations, and general background levels. More details concerning this procedure are presented in Appendix H. Equation (F1) is used to estimate the appropriate emission density.

$$Q = \frac{[(EF)\ (V)\ (RT)]_{auto} + [(EF)\ (B)\ (RT)]_{buses}}{216{,}000\ A} \qquad (F1)$$

The discussion in Appendix A concerning microscale impact analysis may be used to estimate the impact of freely flowing and/or queuing traffic on nearby CO concentrations. Equation (A11) is used to estimate the impact of freely flowing traffic. If traffic at a signalized intersection is of interest, excess emissions over a finite queue [obtained using Equations (A18) and (A19)] are added to emissions estimated for line sources of freely flowing traffic with Equation (A11). Emissions near a non-signalized intersection may be approximated with Equations (A20) - (A23) and with Equation (A11).

FIV. Qualitative Guidelines

Consideration of the following unquantified principles in the design and review of amusement parks should be of help in diminishing the impact of the park on air quality.

1. Since the layouts of amusement parks can usually be modified comparatively easily to accommodate larger crowds or to alleviate traffic problems, the amount of space available for expansion or modifications should be checked. Specifically, the ease with which parking capacity and access roads could be expanded should be reviewed.

2. The appropriate and adequate use of signs and markers to direct motorists throughout the vehicular areas of the park is important, since many of the guests are tourists visiting the facility for the first time.

3. The developer should demonstrate an effort to optimize traffic circulation patterns in the park by such methods as:

    No left turn movements across the main access roads

    Maximum use of one-way and divided streets

    Markings that separate parking lot entrance lanes from through traffic lanes, where appropriate

    Prohibition of on-street parking within the park.

4. In addition to the employees normally assigned to parking and traffic control, the park's security personnel should be available to assist in these areas during peak periods.

REFERENCES

(1) Axetell, K., Jr. and Thayer, S. D.; "Vehicle Behavior In and Around Complex Sources and Related Complex Source Characteristics: Volume V--Amusement Parks;" EPA-450/3-74-003e; (Nov. 1973); National Technical Information Service; Springfield, Va. 22161.

(2) Kunselman, P., H. T. McAdams, C. J. Domke and M. Williams; "Automobile Exhaust Emission Modal Analysis Model;" EPA-460/3-74-005; (January 1974); National Technical Information Service, Springfield, Va. 22161.

(3) "Compilation of Air Pollutant Emission Factors;" EPA Publication No. AP-42; (Second Edition); Supplement Number 5; (In Press).

(4) 40 CFR 85; "1975 Federal Test Procedure;" Federal Register 36, No. 128; (July 2, 1971).

(5) Williams, M. E., J. T. White, L. A. Platte, and C. J. Domke; "Automobile Exhaust Emission Surveillance--Analysis of the FY 72 Program;" EPA-460/2-74-001; (February 1974); National Technical Information Service; Springfield, Va. 22161.

(6) Ashby, H. A., R. C. Stahman, B. H. Eccleston and R. W. Hurn; "Vehicle Emissions--Summer to Winter;" Paper No. 741053 presented at the SAE Automobile Engineering Meeting; Toronto, Canada; (Oct. 21-25, 1974); Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pa. 15096.

(7) Hillier, F. S. and Lieberman, G. J.; Introduction to Operations Research; Holden-Day, Inc.; San Francisco, Calif.; (1967); Ch. 10.

(8) Newell, G. F.; "Approximate Methods for Queues with Application to the Fixed Cycle Traffic Light;" SIAM Review 7 No. 2; (1965).

APPENDIX G. METHOD FOR ESTIMATING EMISSIONS AT RECREATIONAL AREAS

This appendix is intended to provide guidance concerning a more detailed analysis of proposed indirect sources should this be necessary or desirable pursuant to 40 CFR 52.22(b). The materials contained herein are offered as suggestions. Alternate analytical approaches for evaluating the impact of a proposed source may be used if it can be demonstrated that they are more applicable to the source under review.

U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, N.C. 27711

January 1975

APPENDIX G.

METHOD FOR ESTIMATING EMISSIONS AT RECREATIONAL AREAS

The purpose of this Appendix is to provide a means for assisting air pollution control agencies, planning agencies or developers to estimate vehicular emissions occurring during the operation of a recreational area. Recreational areas are extremely varied in type, purpose, size, administrative control source and degree of patronage. The analysis in this Appendix is specifically addressed toward National and State parks. However, the Appendix may be of use in identifying a methodology which may be adaptable to other types of recreational areas as well.

Section GI of this Appendix summarizes a methodology which could be used to estimate CO emissions occurring within and in the vicinity of a recreational area's parking facilities. A procedure for estimating emissions from traffic lanes in access roads, at nearby intersection approaches and at exit/entrance gates is also summarized. The remaining portions of the Appendix discuss how the methodology described in Section GI might best be implemented.

GI. Procedure for Estimating Emissions in the Vicinity of a Recreational Area's Parking Facilities

1. Obtain estimates for the key design and operating parameters identified in Table G1.

2. If available, apply data concerning observed driving cycles at existing recreational area parking facilities in the EPA Automobile Exhaust Emission Modal Analysis Model to obtain average trip automobile emission factors (EF) for automobiles utilizing the recreational facility. If this approach is not feasible, use Figure G1 and Eq. (G2) if necessary to obtain an automobile emission factor for CO. Use Sections 3.1.4.3 and 3.1.5 of Supplement 5 to AP-42 and Eq. (G3) to obtain appropriate emission factors for buses. Use Section 3.1.4.3 of Supplement 5 to AP-42, and Eq. (G4) to estimate CO emission factors for heavy-duty campers (EF) if there are likely to be significant numbers of these vehicles utilizing the area. If appropriate local data concerning the nature of operation and the mix of local vehicles are available, multiply the emission factor by a local correction factor. Guidance in Section 4.4 of the screening procedure and in Supplement 5 to AP-42 may be used to derive correction factors for differing percentages of cold starting vehicles, ambient temperatures and altitudes.

3. Quantify diurnal daily use patterns using Eqs. (G7a) or (G7b). and use these in Eq. (G6) to estimate the traffic volume demand (V).

4. Estimate base running time (BRT) from the parking area's physical configuration and the recreational area's operating policy using expressions similar to (G8a) - (G8g) and Eq. (G9).

5. If the parking lot is full, estimate the amount of extra running time to move to an overflow lot using Eq. (G10).

6. Apportion entering and exiting traffic among entrances and exits using Eqs. (G12) and (G13) or (G14) and (G15). Estimate the excess running time spent in queues at each exit and entrance not having a traffic signal using Eqs. (G11) or (G17) or (G18). Use Eq. (G19) to estimate excess

running time at exits/entrances having traffic signals. Estimate averages excess running time spent in entrance/exit queues using Eq. (G20).

7. Estimate average running time per trip (RT) using Eq. (G21).

8. Use Eq. (G1) to estimate the emission density at a recreational area's parking lots.

9. Refer to the microanalysis section in Appendix A to estimate the impact of freely flowing and/or queuing traffic on nearby CO concentrations. The procedure is as follows:

a. Estimate traffic demand for each lane j in road segment i using Eqs. (A12) or (A13). If necessary, adjust the demand for the impact of mass transit using Eqs. (A14) or (A15). Apportion demand among lanes, making sure that Eq. (A2) is satisfied.

b. If the analysis does not concern an at-grade intersection, estimate capacity of the road segment using Eq. (A10) and the lane capacities using Eq. (A16). Check that Eq. (A3) is satisfied. If not, adjust the lane capacities so that Eq. (A3) is satisified.

c. Determine volume to capacity ratios (v_{ij}/c_{ij}) for each lane. Given the type of road and the average highway speed, use the appropriate one of Figures A2-A5 to estimate vehicle operating speeds in each lane.

d. Use Fig. A6 to estimate the speed corrected 1975 emission factor for each lane. For years other than 1975, adjust this factor with Equation (A17). Use guidance in Section 4.4 of the screening procedure or in Supplement 5 to AP-42 to correct for cold starts and ambient temperature, as needed.

e. Use Eq. (A11) to estimate the line source emission intensity of freely flowing traffic.

f. For at-grade signalized intersections, use information concerning signal cycle lengths and green time to signal cycle ratios, to estimate queue lengths with Eq. (A18). Consider emissions over the queue length to be the sum of those from freely flowing traffic and excess emissions. Use emissions attributable to freely flowing traffic elsewhere. Estimate emissions from freely flowing traffic using Eq. (A11), and excess emissions using Eq. (A19). Alternatively, use the information in Tables A8-A12 directly to estimate appropriate emissions and queue lengths.

g. For non-signalized intersections, estimate the average queue length using Eq. (A20). Use Eq. (A21) to estimate the emission intensity over the queue at the intersection approach. Estimate the distance over which vehicles may accelerate and decelerate using Eq. (A22). The emission intensity over this distance is obtained using Eq. (A23). Use Eq. (A11) to estimate emission intensity elsewhere.

GII. Identification of Key Design and Operating Variables

Recreational area design and operating parameters are delineated into 2 categories: those essential to estimating emissions, and those highly desirable, both to be provided by the developer. If the developer cannot provide the highly desirable parameters, "best estimates" have been provided. These parameters are used to estimate vehicle running times and peak traffic demand which, in conjunction with vehicle emission factors, are used to estimate vehicular emissions.

Two key elements in the design of a recreational area become evident in assessing the area's impact on emissions:[1]

1. The entrance capacity must be sufficient to handle peak arrival rates without creating long entrance queues, and

2. The number of parking spaces must be sufficient to accomodate the peak accumulation of vehicles in the lots or an efficient operational means should be used to route access traffic to overflow parking areas.

Table G1 presents the essential and highly desirable recreational area parameters which the developer or future administrator should provide.

Table G1. RECREATIONAL AREA PARAMETERS NEEDED FOR AIR QUALITY IMPACT ANALYSIS

I. Essential Parameters

Parameters	Remarks
Peak Capacity	Maximum number of visitors that can be accommodated with the existing park facilities
Anticipated diurnal arrival and departure patterns	Percent of total arrivals anticipated for entering and leaving vehicles during each hour of the park's operation on days with anticipated capacity crowds
Available visitor parking spaces	
Physical layout and dimensions of the recreational area's parking facilities	Needed to help estimate running times and identify locations with heaviest congestion
Percent of crowd arriving by automobile	
Number of buses expected	

Table G1 (continued) RECREATIONAL AREA PARAMETERS NEEDED FOR AIR QUALITY IMPACT ANALYSIS

Parameters	Remarks
Number of camper type vehicles expected	
Gate capacities	Number of vehicles which can be accommodated through each entrance (exit) per unit time
Green time to signal cycle ratio at nearby intersection approaches	Needed to estimate intersection approach capacities and queue lengths on approaches during the red phase
Number of signal cycles per hour at each nearby intersection	Needed to estimate queue lengths on each approach to each intersection during the red phase for each approach
Traffic volume demand and capacities for access roads and at nearby intersection approaches	Needed to estimate the recreational area's impact at nearby intersection approaches

Table G1 (continued) RECREATIONAL AREA PARAMETERS NEEDED FOR AIR QUALITY IMPACT ANALYSIS

Parameters	Remarks
II. Highly Desirable Parameters	
Base running time (BRT)	Total time a typical vehicle is likely to spend with the engine on while arriving and leaving the park during periods with little or no congestion
Average vehicle occupancy	The average number of visitors expected per vehicle during periods with capacity crowds
Estimated ratio of people in the park at the most crowded time of the day total daily attendance	
Estimated time required for vehicles to move to auxiliary lots when the parking capacity in the main lot is exceeded	
Distribution of vehicles through exit/entrance gates	

Referring to Table G1, peak capacity provides an indicator of the maximum number of vehicles likely to utilize the area's parking lots during a day. Anticipated diurnal arrival and departure patterns are critical in determining the number of vehicles running in a park's lot during the peak 1- and 8-hour use periods. Available parking spaces and gate capacities are extremely important in determining how congested a lot is likely to become with peak use rates. Percent of crowd likely to arrive by automobile, number of camper type vehicles, and number of buses likely to be present are important parameters in that they enable better estimates of peak traffic volume demand to be made, given crowd projections. Average vehicle occupancy is a highly desirable parameter because it provides a means for estimating traffic volume from crowd projections. Ratio of people in the park to total daily attendance is also desirable because it facilitates an estimate of peak occupancy in the parking lot. Base running time is of importance because it is needed to estimate typical emission levels with little congestion, while the excess time required to move to auxiliary lots may be of interest during periods of peak use. Distribution of traffic volume demand among exit/entrance gates and access roads is needed in estimating whether congestion is likely to occur at these key locations.

GIII. Estimating Emissions in the Vicinity of a Recreational Area's Parking Facilities

Two types of analyses are necessary in estimating vehicular emissions in and around a recreational area's parking facilities. First CO emission density attributable to vehicles utilizing the recreational area's parking facilities plus emission rates for significant stationary sources (using Volume 10 of the "Guidelines for Air Quality Maintenance Planning and Analysis")[2] should be estimated. Second, vehicular emission rates resulting in traffic lanes in locations most susceptible to congestion (i.e. at exit/entrances or intersection approaches) should be estimated.

A. Emission Density

For parking lot (area source) activity, the emission density (Q) is given by:

$$Q = \frac{\left[[(EF)(V)(RT)]_{autos} + [(EF)(V)(RT)]_{buses} + [(EF)(V)(RT)]_{\text{camper-type vehicles}}\right]}{216{,}000\ A} \quad \text{(G1)}$$

where EF = emission factor, gm/min-veh,

V = traffic volume demand, veh/hr,

RT = running time spent in a typical trip* entering or leaving the lot, sec,

A = parking lot area, m^2

Q = emission density, $gm/sec\text{-}m^2$

Specific account of emissions from buses and campers may be desirable in Eq. (G1), if large proportions of these vehicles use the area, because emission factors for buses and campers may be appreciably different than for autos. In addition, if separate parking facilities are provided for buses or large campers, running times for these vehicles may be different than for autos.

1. Estimating Emission Factors

(a) Automobiles

Probably the most accurate estimate of CO emission factors at recreational areas could be obtained if typical driving cycles

---

*A trip is a one-way visit to the recreational area. A typical vehicle makes two trips--one coming, one going.

(i.e. sequence and amounts of time spent in acceleration, deceleration and steady speed modes of travel) could be estimated explicitly for recreational area parking facilities. Such a driving cycle could then be simulated with EPA's Automobile Exhaust Emission Modal Analysis Model[3] to obtain average trip emission factors for recreational area parking facilities. This approach has been followed in characterizing emissions at signalized intersections in Appendix A. Unfortunately, the data to implement such a technique elsewhere at a recreational facility may be difficult to obtain. Consequently, use of CO emission factors based on the 1975 Federal Test Procedure (FTP)[5] for typical national mixes of model years is proposed as an alternative. Figure G1 was obtained using the FTP trip emission factor for CO presented in Tables A3, Appendix A for 1975 mix of light-duty vehicles (88 percent autos, 12 percent light trucks) and Tables 3.1.2-6a and b of Supplement 5 to AP-42 to obtain appropriate speed correction factor (c(s)). Note that emissions corresponding to 0 mph are indicative of stop-and-start traffic rather than idle. Equation (G2) should be used to estimate emission factors for vehicle mixes during years other than 1975.

$$EF = \begin{bmatrix} \text{emission factor obtained} \\ \text{from Fig. G1} \end{bmatrix} \left(\frac{ef}{55}\right) \tag{G2}$$

where ef = CO emission factor obtained from Table A3, Appendix A for the year of interest, gm/mi-veh

"55" = CO emission factor for 1975 from Table A3, gm/mi-veh

EF = emission factor, gm-min-veh.

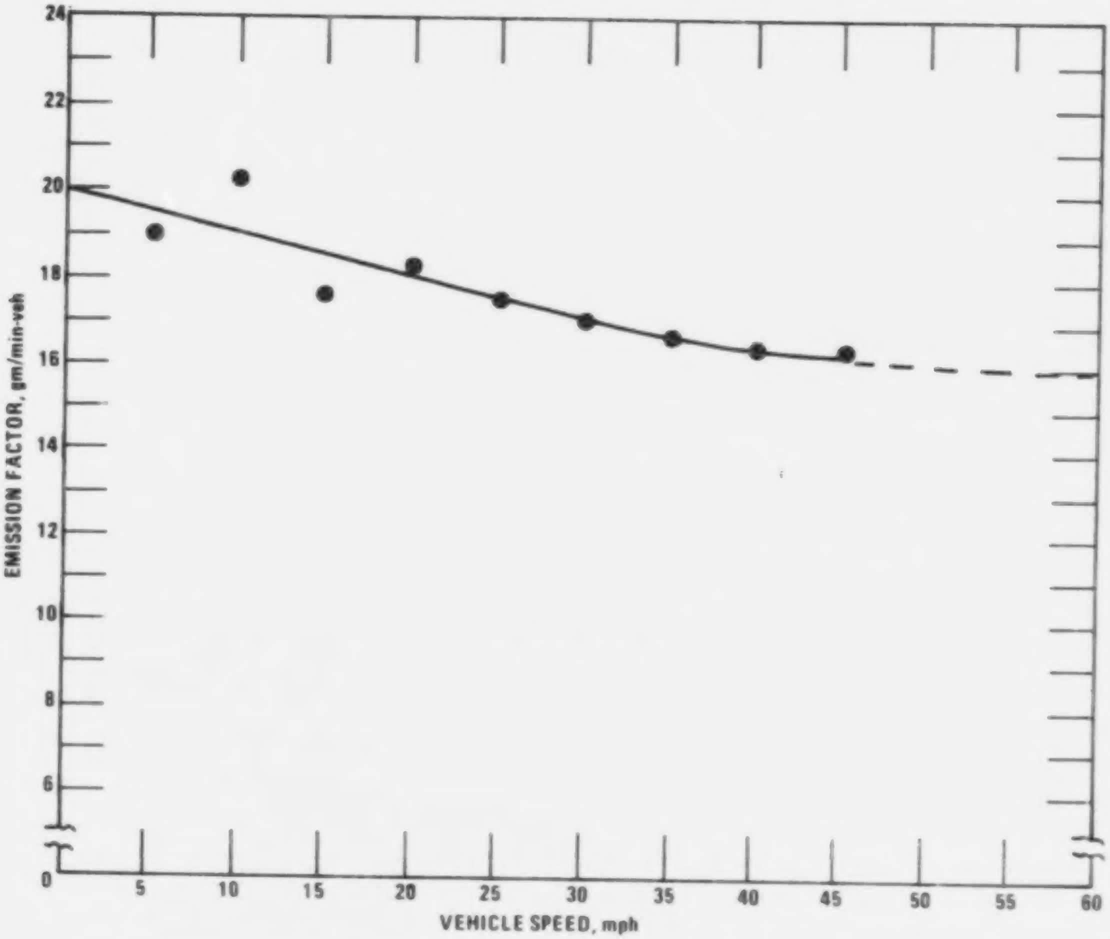


Figure G1. Composite emission factors for carbon monoxide for calendar year 1975.

(b) Buses

Sections 3.1.4.3 and 3.1.5 in Supplement 5 to AP-42 provide emission factors (in gm/mi-veh) for heavy-duty gasoline and diesel-powered vehicles respectively. Once the appropriate emission factor for gasoline and diesel-powered buses is estimated from AP-42, a bus CO emission factor with units suitable for use in Eq. (G1) can be calculated using Eq. (G3).

$$EF = \left(\frac{\text{Emission factor obtained from Fig. G1}}{(ef)}\right)\left[\frac{(\#\text{ gas. buses})\ (ef)_g + (\#\text{ diesel buses})\ (ef)_d}{(\text{Total }\#\text{ of buses})}\right] \qquad (G3)$$

where $(ef)_g$ = the estimated emission factor for heavy-duty gasoline-powered vehicles as determined from Section 3.1.4.3 in Supplement 5, AP-42, gm/mi-veh,

$(ef)_d$ = the estimated emission factor for heavy-duty diesel-powered vehicles as determined from Section 3.1.5 in Supplement 5 to AP-42, gm/mi-veh,

(ef) = emission factor for light-duty vehicles, estimated from Table A3, gm/mi-veh.

(c) Camper-type Vehicles

EPA is presently investigating the effect of trailers on automobile emissions. Until this study is complete, automobiles pulling camper trailers and camper trucks (pick-ups mounted with camper shells and accompanying equipment) should be assumed to have the same emission factor as automobiles without trailers. Vehicles such as Winnebagos and other "houses on wheels" weighing more than 6000 lb. (gross vehicle weight), however, are heavy-duty vehicles and should be considered as heavy-duty gasoline-powered vehicles if found in significant numbers.

The camper trailer emission factor in the proper units is given by:

$$EF = \left[\frac{\text{Emission factor obtained from Fig. G1}}{(ef)}\right](ef)_g \qquad (G4)$$

where $(ef)_g$ = estimated emission factor gasoline-powered heavy-duty vehicles from Section 3.1.4.3 in Supplement 5 to AP-42, gm/mi-veh.

(ef) = emission factor for light-duty vehicles (gm/mi-veh) estimated from Table A3, gm/mi-veh.

In equations (G2), (G3) and (G4) the effect of speed on emissions is assumed the same for all types of vehicles. Although the emission factor obtained from Fig. G1 and the (ef) in Equations (G2)-(G4) are not themselves applicable to all types of vehicles, under the above assumption, the ratio of these two emission factors is the same for all vehicle types. The procedure described above makes a number of assumptions about the mix of vehicles, percentage of cold starts, altitude factors, etc. These assumptions are documented in Appendix A. If local data are available which indicate these assumptions are not applicable, the emission factor obtained should be multiplied by a local correction factor. If the assumptions concerning altitude, percentage of cold starts and ambient temperatures used in deriving an emission factor are not appropriate, guidance in Section 4.4 of the screening procedure or in Supplement 5 to AP-42 may be used to derive a correction factor to the estimates. It should be pointed out that if it is determined that extra emissions attributable to cold starts and cold temperatures only occur for a relatively short time (e.g., 4 minutes), higher emission factors should be used only until a typical vehicle becomes warm.

2. Estimating Traffic Volume Demand (V)

For any number of hours, the traffic volume demand can be estimated using Equation (G6).

$$V = \frac{(P)(d_t)(G)}{(avo)} + d'_t B \qquad (G6)$$

where P = fraction of the crowd arriving by automobile

d_t = average hourly fraction of total daily automobile and camper arrivals and departures occurring during time period "t"

d'_t = ave. hourly fraction of total daily heavy duty vehicle arrivals and departures occurring during time period "t"

G = estimated peak total daily admission tickets sold (i.e., equal to peak capacity parameter in Table G1)

avo = average automobile occupancy for visitors

V = traffic volume demand, veh/hr

B = heavy duty traffic demand, veh/hr

Estimates of the parameters "G," "B," and "P" must be supplied by the developer and would be used directly in Eq. (G6). The parameter "d_t" is derivable from the estimates of diurnal arrival and departure patterns required from the developer, as shown by Eqs. (G7a) and (G7b).

$$d_t = \frac{(\text{\# of arrivals + \# of departures})_t}{(\text{\# of arrivals on the peak day})\ (t)} \qquad (G7a)$$

or

$$d_t = \frac{\begin{matrix}\text{(Fraction of total} \\ \text{daily arrivals)}_t\end{matrix} + \begin{matrix}\text{(Fraction of total} \\ \text{daily departures)}_t\end{matrix}}{t} \qquad (G7b)$$

where t = number of hours in time period t, hr.

Unless there are explicit indications to the contract, d_t can be assumed equal to d_t. Average visitor vehicle occupancy (avo) is a highly desirable parameter for the developer to provide. However, if this is not possible, past observations [1] have indicated typical automobile occupancy of about 3.5 persons/vehicle. Therefore, in the absence of better information, a value of "3.5" should be assumed for (avo).

While the anticipated diurnal arrival and departure patterns are required information, it is recognized that they may be somewhat difficult to estimate. The information in Table G2 is based on observations at existing recreational areas,[1] and is provided as a guide. In the absence of better information the values for "d_t" in Table G2 may be used.

Table G2. DIURNAL USE PATTERN PARAMETERS OBSERVED FOR EXISTING RECREATIONAL AREAS

Time Period, t	d_t
1 hour	.18
8 hours	.16

3. Estimating Average Trip Running Time (RT)

Eight vehicular operational modes have been identified as contributing to total vehicle running time. These are:

(a) Approach Mode--Time vehicle spends running on access road (usually on park property) during which traffic movement is strongly affected by vehicles entering or leaving the area's parking facilities;

(b) Entrance Mode--Waiting and service time at the gate or entranceway to the parking lot;

(c) Movement-In Mode--Driving time to the designated parking space;

(d) Stop Mode--Parking time;

(e) Start Mode--Time required for egress from parking space;

(f) Movement-Out Mode--Driving time from parking space to preferred exit;

(g) Exit Mode--Time required to move through exitway;

(h) Departure Mode--Driving time along immediate access road during which movement continues to be influenced by traffic from the recreational area's parking facilities.

The total running time for a typical vehicle is the sum of the time spent in the 8 modes during periods with little congestion, plus any extra time resulting from congestion of the facility during peak usage periods. The time required during periods of little congestion is referred to as the base running time (BRT) and ideally should be provided by the developer. If this estimate is not available, it can be obtained by studying the facility's physical configuration and proposed operating policies. An example of the procedure used in estimating BRT is depicted by the following expressions.

$$\text{Base Approach Time} = \frac{\begin{array}{l}\text{(Distance between entrance and nearest}\\ \text{intersection on the access road, m)}\end{array}}{\text{(Posted speed limit, m/sec)}} \tag{G8a}$$

$$\text{Base Entrance Time} = \frac{1}{\text{(Main Entrance gate capacity, veh/sec)}} \tag{G8b}$$

$$\text{Base Movement-In Time} = \frac{\begin{array}{l}\text{(Distance from center of lot to main entrance)}\\ \text{measured along traffic lanes, m}\end{array}}{\text{(Speed limit in lot m/sec)}} \tag{G8c}$$

$$\text{Base Stop, Base Start Time} = \begin{array}{l}\text{5-10 sec each depended on angle of parking}\\ \text{and lane width}\end{array} \tag{G8d}$$

$$\text{Base Movement-Out Time} = \frac{\begin{array}{l}\text{(Distance from center of lot to main exit)}\\ \text{Measured along traffic lanes, m)}\end{array}}{\text{(Speed limit in lot, m/sec)}} \tag{G8e}$$

$$\text{Base Exit Time} = \frac{1}{\text{(Main exit gate capacity, veh/sec)}} \tag{G8f}$$

$$\text{Base Departure Time} = \frac{\begin{array}{l}\text{(Distance between main exit and nearest}\\ \text{intersection on the access road, m)}\end{array}}{\text{(Posted speed limit, m/sec)}} \tag{G8g}$$

$$\text{BRT} = (\text{G8a}) + (\text{G8b}) + (\text{G8c}) + (\text{G8d}) + (\text{G8e}) + (\text{G8f}) + (\text{G8g}) \tag{G9}$$

Since both entering and leaving traffic are counted in estimating peak traffic volume demand, use of the total BRT to estimate running time would result in an inappropriately high estimate.

In most cases the value which can be used would simply be BRT/2. This assumes that, with little or no congestion, running time is about equally divided between entering modes (modes a-d) and leaving modes (modes e-h). If the developer's estimates for base running times in each mode indicate that this simplifying assumption is inappropriate, it would be necessary to perform separate emission calculations for entering and leaving traffic. This analysis would be performed similarly to the methods described in this Appendix, except that only that portion of the peak volume demand which was due to entering traffic would be associated with running times in modes (a-d) and only that portion of peak volume demand attributable to leaving traffic would be associated with running times in modes (e-h).

Running times for 3 of the 8 operating modes may be appreciably affected by congestion. The three modes are: the movement in, entrance and exit modes. Time spent in the movement-in mode is increased if the main lot is full and the arriving visitors are forced to drive to an auxiliary parking area. This extra movement-in time, Δ_{MI}, is one of the "desirable parameters" called for in Table G1. If it is unavailable from the developer, it should be estimated using the physical plan and dimensions of the park's parking area provided by the developer. Unless the physical plan makes it inappropriate, Eq. (G10) could be used as a guidepost for estimating Δ_{MI}.

$$\Delta_{MI} = \frac{\begin{pmatrix}\text{Dist. from center of main} \\ \text{lot to main lot exit measured} \\ \text{along traffic lanes, m}\end{pmatrix}}{(\text{posted main lot speed limit, m/sec})} + \frac{\begin{pmatrix}\text{Dist. between main lot exit} \\ \text{and auxiliary lot entrance, m}\end{pmatrix}}{(\text{posted speed limit, m/sec})}$$

$$+ \frac{\begin{pmatrix}\text{Dist. between auxiliary lot entrance} \\ \text{and center of the lot measured} \\ \text{along traffic lanes, m}\end{pmatrix}}{(\text{posted auxiliary lot speed limit, m/sec})} \qquad (G10)$$

where Δ_{MI} is in seconds.

If the main parking lot is not full, Δ_{MI} is assumed to be zero. Whether or not the main lot is full, can be determined by examining the diurnal arrival-departure patterns provided by the developer, the resulting peak traffic demands on a peak day and the number of parking spaces in the main lot.

Increased running times may also occur when the exiting traffic volume demand approaches the gate's exit capacity and/or entering traffic volume demand at a gate approaches the access road's capacity to accommodate right and left turns, or a gate's entrance capacity, whichever applies. When this happens queues form at the exit (entrance) thereby increasing running times. The increase in running time for each lane of traffic at gate i is obtained for a non-signalized exit/entrance from queuing theory by Equation (G11)[8].*

$$RT_{qi} = \frac{3600}{c_i} \left(\frac{v_i}{c_i - v_i} \right), \ v_i/c_i < .95 \qquad (G11)$$

---

*Separate analysis should be performed for entering and exiting traffic.

where RT_{qi} = time spent in the exit or entrance queue at gate i, sec

c_i = exit or entrance capacity of gate i (obtained from developer) veh/hr

v_i = exit or entrance traffic volume demand at gate i, veh/hr

For exiting traffic, the parameter "v_i" is obtained by apportioning the exiting traffic volume demand among exit gates. Ideally, the apportionment of exiting traffic should be provided by the developer and should be based on the orientation of the recreational area with respect to population centers. Entering traffic should be apportioned directionally on the access road, and the traffic in each direction should be set equal to the "v_i" in Eq. (G11). The excess running time spent entering entrance i would be the mean value of the excess time spent in each direction on the access road. If the apportionment is not provided, two apportioning procedures are suggested below.

(a) Apportion exiting and entering traffic according to access road capacities.

$$E_i = [E] \frac{\text{(capacity of access road to gate i)}}{\text{(capacity of all access roads)}} \qquad \text{(G12)}$$

where E_i = traffic entering demand at gate i during the 1- or 8-hr. period of interest, veh/hr

E = total traffic entering demand during the 1- or 8-hr. period of interest, veh/hr

and

$$X_i = [X] \frac{\text{(capacity of all access roads to gate i)}}{\text{(capacity of all access roads)}} \qquad \text{(G13)}$$

where X_i = traffic exit demand from gate i during the 1- or 8-hr. period of interest, veh/hr.

X = total traffic exit demand during the 1- or 8-hr. period of interest, veh/hr.

(b) If access road capacities are unknown, or if more than one gate empties onto the same access road, apportion traffic according to gate capacities.

$$E_i = [E] \frac{\text{(entrance capacity of gate i)}}{\text{(entrance capacities of all gates)}} \qquad \text{(G14)}$$

and

$$X_i = [X] \frac{\text{(exit capacity of gate i)}}{\text{(exit capacity of all gates)}} \qquad \text{(G15)}$$

It should be noted that the traffic volume demand is:

$$V = X + E \qquad \text{(G16)}$$

If the entering or exiting traffic demand at a gate is estimated to be greater than 95% of the gate's entrance or exit capacity, the excess running time spent in queues should be estimated using Eq. (G17) or Eq. (G18).

$$RT_{qi} = 3600\ (20/c_i) \qquad \text{(G17)}$$

If $v_i/c_i > 1$,

$$RT_{qi} = 3600 \quad 20/c_i + \frac{v_i - c_i}{2\ c_i} \tag{G18}$$

where "3600" is the number of seconds in the 1-hr. period in which the demand exceeds the capacity (sec), and the other terms are as defined for Equation (G11).

Excess running time spent entering or exiting from a parking lot with signalized exit/entrances may be estimated using Equation (G19)[9] rather than (G11) or (G17).

$$RT_{q\ i} = \left[\frac{(C_y)\ (c')\ (1-G/C_y)^2}{2\ (c' - v)} + \frac{1800\ v\ C_y^{\ 2}}{c'\ G\ (c'\ G - v\ C_y)}\right]_i \tag{G19}$$

where $RT_{q\ i}$ = excess running time spent entering or exiting at entrance/exit i, sec

C_y = signal cycle length, sec

c' = unimpeded capacity at a signalized intersection approach of interest, veh/hr

G = amount of green time per signal cycle for the intersection approach of interest, sec

G/C_y = green time to signal cycle ratio, dimensionless

v = traffic demand at the intersection approach of interest, veh/hr.

If $v = c'$, use Equation (G18) instead.

Equation (G18) assumes that the hour of interest is the first in which demand exceeds capacity at gate i. If this were not the case, it would be necessary to go back to the first hour in which the entrance (or exit) demand (v_i) at gate i exceeded gate i's entrance (or exit) capacity and compute the queue building during each succeeding hour until the period of interest, t, is reached. For example, if demand first exceeded capacity 2 hours prior to the period of interest, average excess running time would be estimated by Equation (G18a).

$$RT_{qi} = 3600\left[20/c_i + \frac{\left[(v_i-c_i)_{t-2} + (v_i-c_i)_{t-1} + (v_i-c_i)_t\right]}{2\ c_i}\right] \qquad \text{(G18a)}$$

The average excess running time spent by vehicles in entrance and exit queues at the recreational areas's parking facilities is estimated by Equation (G20).

$$\overline{RT}_q = \frac{\sum\limits_{\text{all } i} RT_{qi}}{I} \qquad \text{(G20)}$$

where I = the total number of entrance + exit gates.

Equation (G21) can now be used to estimate average running time spent by a vehicle on one trip to or from the recreational area.

$$RT = \frac{BRT}{2} + \Delta_{MI}\left[\frac{\text{entering traffic}}{\text{total traffic}}\right] + \overline{RT}_q \qquad \text{(G21)}$$

The base running time (BRT) is divided by "2," because each trip is a one-way trip. Thus, in determining average daily trip generation rate (from which volume demand is derived), each vehicle is counted twice. Since BRT refers to the total time required to enter and leave a recreational area's parking lot, it should be divided by "2."

B. Estimating Peak Impacts Within or Near the Parking Lot or on Access Roads Removed from the Lot

Peak concentrations of CO are likely to occur in the vicinity of exit/entrances to the lot, near access roads or at nearby intersections. Traffic at such locations may be characterized as line sources of pollution. Two situations are of interest: the case where traffic flows freely by the receptor; and the case where queues form in the vicinity of the receptor. At traffic lanes within or adjacent to the parking lot, the impact of freely flowing and/or queuing vehicles on CO concentrations in the vicinity of the lanes should be added to estimates obtained using an area source model relating the source's upwind dimension and emission density to CO concentrations and general background levels. More details concerning this procedure are presented in Appendix H. Equation (G1) is used to estimate the appropriate emission density.

$$Q = \frac{[(EF)(V)(RT)]_{autos} + [(EF)(V)(RT)]_{buses} + [(EF)(V)(RT)_{campers}}{216{,}000\ A}$$

The discussion in Appendix A concerning microscale impact analysis may be used to estimate the impact of freely flowing and/or queuing traffic on nearby CO concentrations. Equation (A11) is used to estimate the impact of freely flowing traffic. If traffic at a signalized intersection is of interest, excess emissions over a finite queue [obtained using Equations (A18) and (A19)] are added to emissions estimated for line sources of freely flowing traffic with Equation (A11). Emissions near a non-signalized intersection may be approximated with Equations (A20) - (A23) and with Equation (A11).

GIV. Qualitative Guidelines

Consideration of the following unquantified principles in the design and review of recreational areas should be of help in diminishing the impact of the park on air quality.

1. Since the layouts of recreational areas can sometimes be modified to accommodate larger crowds or to alleviate traffic problems, the amount of space available for expansion or modifications should be checked. Specifically, the ease with which parking capacity and access roads could be expanded should be reviewed.

2. The appropriate and adequate use of signs and markers to direct motorists throughout the vehicular areas of the park is important, since many of the guests may be tourists visiting the facility for the first time.

3. The developer should demonstrate an effort to optimize traffic circulation patterns in the park by such methods as:

No left turn movements across the main access roads,

Maximum use of one-way and divided streets,

Markings that separate parking lot entrance lanes from through traffic lanes, where appropriate, and

Prohibition of on-street parking within the park.

4. During peak traffic periods, employees should be assigned to parking and traffic control.

REFERENCES

(1) Axetell, K., Jr. and Thayer, S. D.; "Vehicle Behavior In and Around Complex Sources and Related Complex Source Characteristics: Volume V--Amusement Parks;" EPA-450/3-74-003e; (Nov. 1973); National Technical Information Service; Springfield, Va. 22161.

(2) U. S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards; "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 10; Reviewing New Stationary Sources;" EPA-450/4-74-011; (September 1974); Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(3) Kunselman, P., H. T. McAdams, C. J. Domke and M. Williams; "Automobile Exhaust Emission Modal Analysis Model;" EPA-460/3-74-005; (January 1974); National Technical Information Service, Springfield, Va. 22161.

(4) "Compilation of Air Pollutant Emission Factors;" EPA Publication No. AP-42; (Second Edition); Supplement 5; (In Press).

(5) 40 CFR 85; "1975 Federal Test Procedure;" Federal Register 36, No. 128; (July 2, 1971).

(6) Williams, M. E., J. T. White, L. A. Platte, and C. J. Domke; "Automobile Exhaust Emission Surveillance--Analysis of the FY 72 Program;" EPA-460/2-74-001; (February 1974); National Technical Information Service; Springfield, Va. 22161.

(7) Ashby, H. A. R. C. Stahman, B. H. Eccleston and R. W. Hurn; "Vehicle Emissions--Summer to Winter;" Paper No. 741053 presented at the SAE Automobile Engineering Meeting, Toronto, Canada; (October 21-25, 1974); Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pa. 15096.

(8) Hillier, F. S. and G. J. Lieberman; Introduction to Operations Research; Holden-Day, Inc.; San Francisco, Ca.; (1967); Ch. 10.

(9) Newell, G. F.; "Approximate Methods for Queues with Application to the Fixed Cycle Traffic Light;" SIAM Review 7, No. 2; (1965).

(10) Highway Research Board; Special Report 87; Highway Capacity Manual 1965; National Academy of Sciences--National Research Council; Washington, D.C.; (1965).

APPENDIX H. USE OF DISPERSION MODELS TO ESTIMATE AIR QUALITY IN VICINITY OF AN INDIRECT SOURCE

This appendix is intended to provide guidance concerning a more detailed analysis of proposed indirect sources should this be necessary or desirable pursuant to 40 CFR 52.22(b). The materials contained herein are offered as suggestions. Alternate analytical approaches for evaluating the impact of a proposed source may be used if it can be demonstrated that they are more applicable to the source under review.

U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

January 1975

APPENDIX H.

USE OF DISPERSION MODELS TO ESTIMATE AIR QUALITY IN VICINITY OF AN INDIRECT SOURCE

The purpose of this appendix is to provide guidance for estimating the impact of a proposed indirect source on air quality. The information contained in Appendix H would be needed if the assumptions underlying the screening procedure presented in the main section of the guidelines were invalid, or if a more complete analysis of a proposed source's impact on air quality is desired. The methods suggested herein are not necessarily the only means by which air quality in the vicinity of a proposed indirect source could be assessed. Alternate techniques could be used if shown to be appropriate for the source under review.

There are two types of estimates which are relevant in assessing the impact of a proposed indirect source on air quality. Of greatest interest is the estimate of peak concentrations in locations where there is a possibility of the general public being exposed for periods greater than or equal to those specified by the primary standards. Also of importance is the impact the source would exert on air quality trends, and on non-deterioration requirements. Assessment of these latter impacts are best done by estimating the effect of the source on representative air quality. Thus, peak concentrations are those which represent the highest concentrations to which the general public is likely to be exposed for 1- or 8-hour periods in the vicinity of the source. Representative concentrations are measures of characteristic concentrations at the site of the indirect source, and provide a means for assessing the source's impact on air quality over larger areas.

This appendix presents methods which could be used to estimate the impact of an indirect source on peak and representative air quality. The curves contained herein are intended to illustrate the sensitivity of the proposed estimation techniques to various meteorological assumptions. Although specific models (i.e., HIWAY and an Area Source Model) are used in these illustrations, other roadway or parking lot models could be used in a modeling analysis of a proposed source if they are appropriately suited for the source under review. If a decision is made to use a modeling approach rather than rely on the screening procedure presented in the Guidelines, it is imperative that the meteorological assumptions used in the analysis be appropriately tailored for use at the proposed site. Ideally, this would include an analysis of data from a nearby observation station, and, in some instances, specific measurements at the site of the proposed indirect source or at similarly situated sources.

HI. Estimation of Peak Concentrations

Estimating peak concentrations in the vicinity of an indirect source is primarily of interest to determine whether the public is likely to be exposed to carbon monoxide concentrations exceeding those specified in the primary standards. This implies that models capable of estimating one and/or eight hour average concentrations of CO must be used. The other Type II pollutants are chiefly of interest because they serve as precursors of oxidants. Since it is suspected that the chemical reactions forming oxidants require some time and mixing in the atmosphere, estimates of hydrocarbon and NO_x emissions and the ensuing representative concentrations are of more interest for these pollutants.

Peak CO concentrations in the vicinity of an indirect source are the result of:

1. General urban background CO concentrations;

2. Concentrations attributable to emissions from traffic related to the source that does not occur within major traffic lanes in the immediate vicinity of the receptor location (e.g., within 100 meters in the case of major traffic lanes);

3. Concentrations resulting from CO emissions from vehicles utilizing nearby major traffic lanes (within 100 m of the receptor).

A. Estimating General Urban Background Concentrations

There are four approaches which could be used to estimate background concentrations at the site of the proposed indirect source. The first approach requires representative air quality data at the site of the proposed source. The second requires emission data and representative air quality data but not necessarily at the site of the source. The third approach requires representative air quality data or emission data, but not both. Finally, the fourth approach addresses the case where no emission or representative air quality data are available. These approaches are discussed in descending order of preference.

1. Use of Air Quality Monitoring Data at Nearby Representative Monitoring Sites

A site should be considered "representative" if it fulfills the criteria set forth in "Guidance for Air Quality Monitoring Network Design and Instrument Siting."[1] Such a site may be either at ground or rooftop level, should be greater than 50 feet from the nearest street curb and be greater than 100 meters from any major thoroughfare. Presence of a representative monitoring site operating for a year in the immediate vicinity of the source's intended location is probably the most reliable method for estimating background concentrations because it inherently takes account of the area's meteorological characteristics and existing source configurations. The monitoring data may be used to estimate background concentrations during times of day in which peak use rates are anticipated. Concentrations observed during periods with poorest atmospheric dilution which occur during the source's proposed operating hours may also be considered to determine whether a greater threat could be posed to the standards by the source during such periods despite the fact that the vehicle use rate may be less than peak during such periods.

Unfortunately there may not be many instances in which a CO monitor is so fortuitously located. If the project is a major one requiring the preparation of an environmental impact statement, it would be highly desirable to obtain monitoring measurements at each prospective site for a period of at least 90 days[2] to use as a means for evaluating the potential impact on air quality attendant.

with each alternative site. More frequently, however, the duration of the monitoring will be limited by the maximum requirements of the indirect source regulations (paragraph 52.22 (b)(3)(i), (b)(3)(iii)(e) and (b)(3)(iv)).[3] If possible, historical data from existing representative monitoring sites should be used as a basis for selecting the time of year in which background concentrations of CO are likely to be highest. Monitoring at the site of the proposed source should occur during such a period. If data are obtained for a limited period during a time of year in which ambient CO levels are likely to be low, the data should be "seasonally adjusted," as described in Section 4.3.1 of the Guidelines, or by some other reasonable approach. If it is not feasible to obtain representative air quality data at the site of a proposed source, it may be necessary to use one of the methods described below for estimating background concentrations.

2. Use of Calibrated Meso-Models

In this discussion, the term "meso-model" refers to an atmospheric dispersion model which can be applied to estimate representative CO concentration patterns about a city. Such models may be used if:

(a) A sufficient emission inventory exists to assign emission densities to designated subdivisions within an urban area, and

(b) Representative air quality data exist, but not necessarily at the site of a proposed indirect source.

In order to use a meso-model it is usually necessary to superimpose a grid over a city and assign emission intensities to each grid square. Alternatively, the receptor site can be regarded as the center of a large circle. The circle is then divided into a number of sectors which are in turn divided into a series of segments. Emission intensities are assigned to each segment within each sector. In terms of convenience of application, meso-models can be divided into two categories: complex models and simple models. Examples of complex models include APRAC-1A,[4*] Climatological Dispersion Model[5*] (CDM) and the Air Quality Display Model.[6] Complex models enable one to estimate the effects of area, point and line sources simultaneously. Examples of simple models include ones proposed by Hanna[7,8] and Gifford and Hanna.[9] Simple models are primarily suitable for area sources. It would be necessary to superimpose the estimates of a point source model over the resulting estimates if point sources are of importance. Simple point source models which may be used include three which are available on UNAMAP.[10*] Fortunately, in many cases the contributions of point sources to representative concentrations of CO may be negligible. Similarly, if a roadway existed in the immediate vicinity of a receptor, a line source model (e.g., HIWAY)[11] would be needed to depict the road's impact. In the case of CO, the background concentrations of greatest interest are ones appropriate for sampling times of 8- and 1-hour duration. The estimates obtained by some of the models cited may not be appropriate for these sampling times (particularly for the 8-hour period). Statistical techniques developed by Larsen[12-14] may be used to obtain estimates of concentrations for appropriate sampling periods given the meso-model estimates. Prior to application of the statistical transformations, the model estimates should be calibrated so that they agree as closely as possible with representative air quality data.

---

*Available on EPA's UNAMAP Time Sharing System.

3. Estimating Background Concentrations with Inadequate Emission or Air Quality Data

Use of directly applicable air quality data or the use of calibrated meso-models to estimate general background concentrations should be made whenever possible. However, if the CO emission inventory is inadequate to use a meso-model and/or there are no representative air quality data available in the vicinity of the site or elsewhere, it may be necessary to estimate background concentrations by one of the other techniques described herein.

(a) Lack of Sufficient Emission Data to Use Calibrated Meso-Models

(1) Availability of Representative Air Quality Data at Several Sites

Background CO concentrations may be estimated at the location of interest by interpolating among the observed or estimated 1- and 8-hour background concentrations at sites where representative CO data are available. Any monitoring site which does not meet the criteria[1] for a representative site should not be included in this interpolation.

(2) Availability of Air Quality Data from One Central City Site not Located at Streetside

It is assumed that the highest background levels for CO occur at central city sites. A central city site is one located in a central business district, not necessarily at the geographical center of the city. If the only air quality data available are from one such site, a possible means for estimating background CO concentrations elsewhere is to assume the concentration diminishes from the maximum level at city center in accordance with Equation (H1).*

$$\chi_r = \chi_c \exp\left[\frac{-r}{(2)\ R}\right] \qquad \text{(H1)}$$

where χ_r = representative CO background concentration at a site located "r" km from the central city site

χ_c = observed CO concentration at a central city site not located within 50 feet of a roadway

r = distance between site of proposed source and the central city monitoring site, km

R = size of central business district, km

If Eq. (H1) yields a value of χ_R less than 1 ppm, set χ_R = 1 ppm.

(b) Lack of Representative Air Quality Data with which to Calibrate Meso-Models

If the emission inventory is sufficiently detailed to allow emission densities to be designated for subdivisions within the area of interest, but there are no representative air quality data (e. g., all CO monitors measure streetside concentrations), meso-models which have been calibrated for other urban areas may be used to estimate background concentrations at the site of the proposed source. Such models would be applied using the emission data compiled for the city in which the source is to be located.

---

*Eq. (H1) is conceptually similar to a technique presented in reference 7 for estimating concentrations in outlying areas. The same assumptions and limitations apply.

4. Use of Representative Air Quality Data from Other Cities

If there are no representative air quality data for the city in which the source is to be located and the emission inventory is inadequate to enable use of a meso-model, "typical" representative CO concentrations obtained in other cities should be used to estimate background concentration. If a choice of cities from which to obtain estimates of background concentrations is available, data should be taken from the city with transportation patterns and meteorological conditions most closely approximating those for the city in which the proposed source is to be located. Publication Number AP-101[15] may provide assistance in identifying cities with similar pollution potentials.

B. Concentrations Attributable to Emissions Generated by the Source which Do not Occur in Major Traffic Lanes within 100 Meters Of a Selected Receptor Site

An area source model is suggested for use in estimating concentrations at a selected receptor which are attributable to emissions generated by the source but not occurring in traffic lanes within 100 meters of the receptor. Relationships among emission density, source size and the impact upon background concentrations of CO can be derived by integrating the equation for an infinitely long line source[16] in the upwind (x) direction as shown in Equations (H2) providing the source and receptor heights are not identical ($h \neq 0$).

$$\chi = \frac{2q\,[\exp(-1/2\,(h/ax^b)^2)]}{\sqrt{2\pi}\,u\,ax^b} \tag{H2a}$$

assuming wind speed (u) and the line source emission intensity (q) are constant with respect to x,

$$\frac{\chi u}{q} \int_{0}^{x'} dx = \frac{2}{\sqrt{2\Pi}} \int_{0}^{x'} \frac{[\exp(-1/2(h/ax^{b})^{2})]}{ax^{b}} dx \qquad \text{(H2b)}$$

or

$$f.\ \chi u/Q = \frac{2}{\sqrt{2\Pi}} \int_{0}^{x'} \frac{[\exp(-1/2(h/ax^{b})^{2})]}{ax^{b}} dx \qquad \text{(H2c)}$$

where

χ = estimated concentration at a selected receptor, gm/m^3

u = wind speed, m/sec

Q = emission density, gm/sec-m^2

h = difference in elevation between source and receptor, m

x' = distance between the receptor and the upwind edge of the indirect source, m

x = upwind distance, m

a,b = constants which depend on atmospheric stability conditions In a Gaussian model, $\sigma_z \sim ax^b$

f = conversion factor from gm/m^3 to ppm

q = line source emission intensity, gm/sec-m.

As a result of Equation (H2c) it is possible to derive a table in which f.χu/Q values are matched against corresponding x' values under a set of assumed stability conditions and for a specified difference in elevation between source and receptor. If one knows the value of f.χu/Q for a given source size (x') and selects a given value of f.χ (e.g., 1 ppm) which is of interest, it is possible to derive the corresponding emission density and to plot an isoconcentration line on a graph relating the upwind dimension to emission density for any given wind speed. This procedure was followed in deriving Figures H1A-E, H2A-E, H3A-E and H4A-E for a wind speed of 1 m/sec. The ordinate on these figures represents the distance between the upwind edge of the area source and the selected receptor site. A similar procedure could be followed to estimate the impact of source-related concentrations under atmospheric stability conditions which may be peculiarly suited for the site of a proposed source.

Figures H1A-3 are applicable for McElroy-Pooler stability classes A-E[17] with an assumed wind speed of 1 m/sec. These stability classifications are believed to be generally suitable for urban areas. Table H1 presents coefficients assumed for the Pasquill-Gifford and McElroy-Pooler stability classes. McElroy-Pooler stability classifications have also been assumed in deriving Figures H2A-E. In addition, Figures H2A-E assume mechanical turbulence resulting from the source configuration and/or the motion of vehicles results in an initial vertical dispersion of CO as large as 10m.[18] Such curves illustrate the impact of a large initial dispersion of CO emissions, and might be particularly appropriate in areas nearby large buildings or in street canyons. Figures H3A-E depict relationships occurring with the more familiar Pasquill-Gifford stability classifications. Finally, Figures H4A-E combine the large initial vertical dispersion assumption with the Pasquill-Gifford stability classifications. The key point to emphasize in using models to estimate the impact of an indirect source on air quality in its vicinity is to take as explicit

Table H1. STABILITY PARAMETER COEFFICIENTS FOR THE VERTICAL PLUME SPREAD PARAMETER

$\sigma_z = ax^b$

Pasquill-Gifford*			McElroy-Pooler*		
Class	a	b	Class	a	b
A	.038	1.28	A	.07	1.28
B	.139	.947	B	.12	1.14
C	.112	.910	C	.23	.97
D	.086	.865	D	.50	.77
E	.082	.816	E	1.35	.51

*Wherever the coefficients vary with distance, values appropriate for the first 500 meters downwind from a source are used in Table H1.

account as possible of the aerodynamic and heat island characteristics of the source site in making assumptions about prevailing atmospheric stability. The foregoing discussion indicates how emission density and source size can be related to the impact of the source on ambient pollutant concentrations given appropriate stability assumptions.

Use of Figures like H1A-E, H2A-E, H3A-E or H4A-E is illustrated in the following example.

Example H1.

(a) Suppose it is of interest to estimate the impact of a parking lot on the 1-hour CO concentration at a receptor site which is not located within 100 m downwind of a major traffic lane. Suppose further it is determined (using methods described in Appendices B-G or by other suitable means) that the indirect source has an emission density of 2.0 x 10^{-4} gm/sec-m^2. Suppose further that the distance from the receptor of interest to the upwind edge of the source is 700 m. Finally, McElroy-Pooler Class D stability and a wind speed of 1 m/sec prevail.

Procedure: Enter Figure H1D along the 700 m ordinate and move to the right until intersecting the χ = 1.0 ppm curve. Note that the corresponding emission density value on the abscissa is 5.4 x 10^{-5} gm/sec-m^2. The estimated impact on the CO concentration at the specified receptor site is given by Equation (H3).

$$\chi = (1\text{ ppm})\left[\frac{\text{Source's Emission Density}}{\left(\begin{array}{l}\text{Abscissa Corresponding to the Intersection}\\ \text{of the Upwind Distance and the 1.0 ppm}\\ \text{Isoconcentration line}\end{array}\right)}\right] \qquad \text{(H3)}$$

Thus, in this example,

$$\chi = (1\text{ ppm})\ \frac{2.0 \times 10^{-4}\text{ gm/sec-m}^2}{5.4 \times 10^{-5}\text{ gm/sec-m}^2}$$

$$\chi = 3.7\text{ ppm}$$

(b) Suppose in the above example, the receptor of interest is assumed to be 200 m downwind from the downwind edge of the source (i.e., 900 m from the source's upwind edge).

Procedure: Enter Fig. H1D at the 900 m ordinate and note the emission density corresponding with the χ = 1.0 ppm curve ($Q = 5 \times 10^{-5}$ gm/sec-m^2). Next, enter Figure 1D at the 200 m ordinate and note the emission density at the intersection with the χ = 1.0 ppm curve is $Q = 8.4 \times 10^{-5}$ gm/sec-m^2. The concentration at the receptor is thus:

$$\chi = \left[\frac{2.0 \times 10^{-4}}{5 \times 10^{-5}}\right](1\text{ ppm}) - \left[\frac{2.0 \times 10^{-4}}{8.4 \times 10^{-5}}\right](1\text{ ppm})$$

$$\chi = 1.6\text{ ppm}$$

It should be noted that the foregoing analysis and Figures H1A-E, H2A-E, H3A-E and H4A-E assume that the cross wind dimension of the source is sufficiently large so that the edge effects are unimportant. This assumption places a limitation on the extent to which the area source models described above can be applied to estimate the impact of the source at receptors not located within or immediately adjacent to the source. A rule of thumb which would be advisable to use is that if the downwind distance between the downwind edge of the source and the

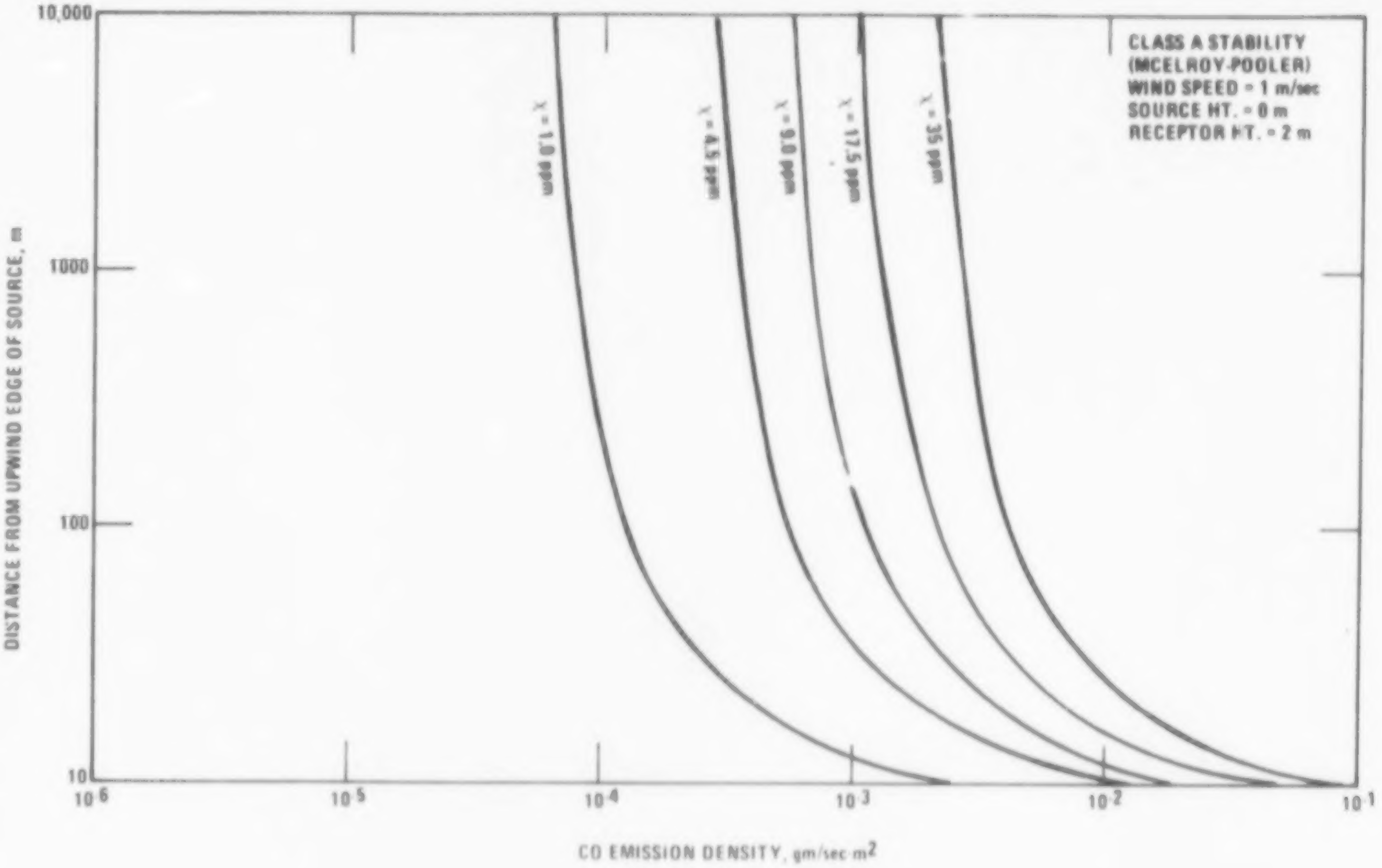


Figure H1A. Relationships among emission density, source size, and carbon monoxide concentrations.

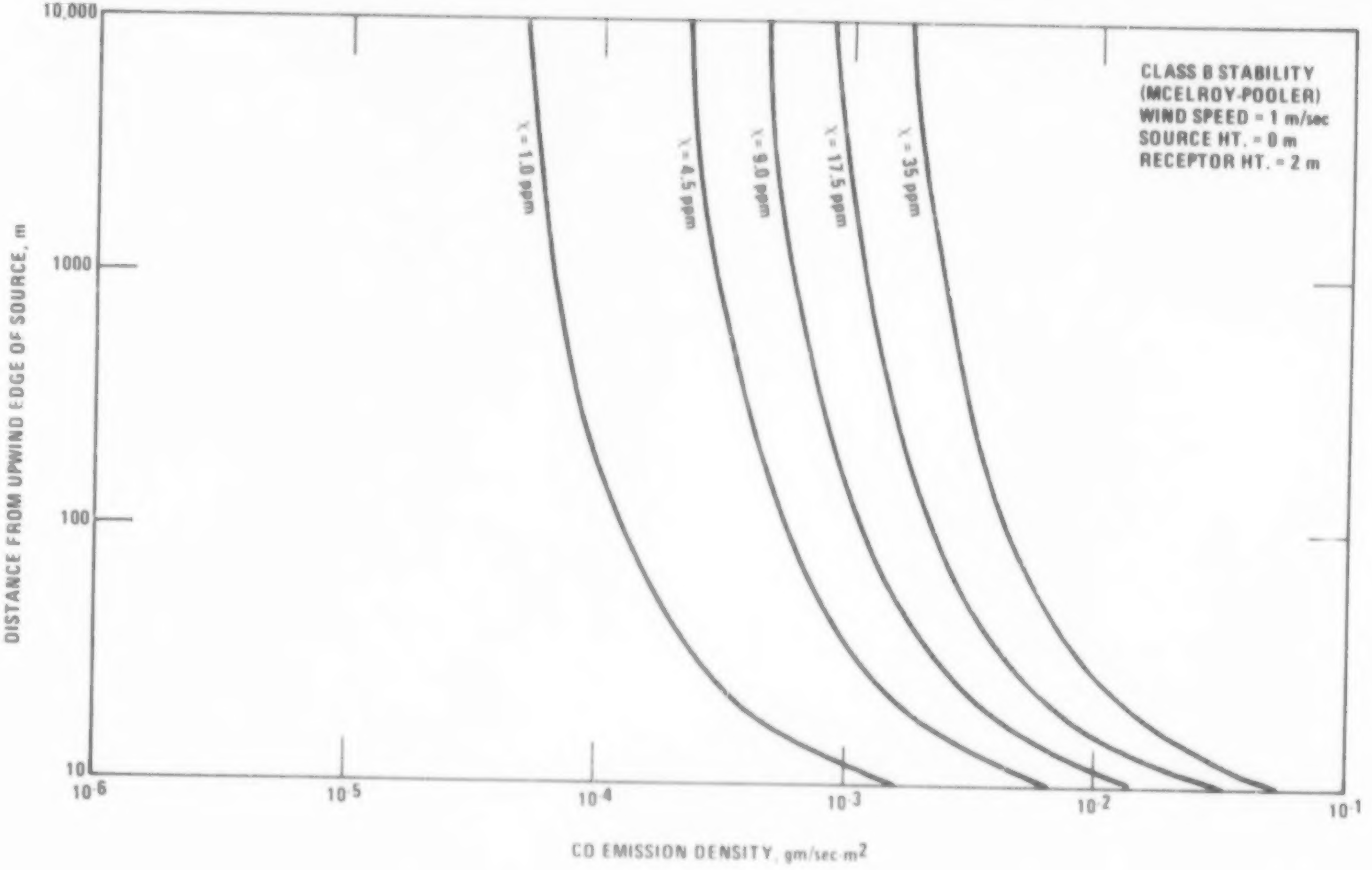


Figure H1B. Relationships among emission density, source size, and carbon monoxide concentrations.

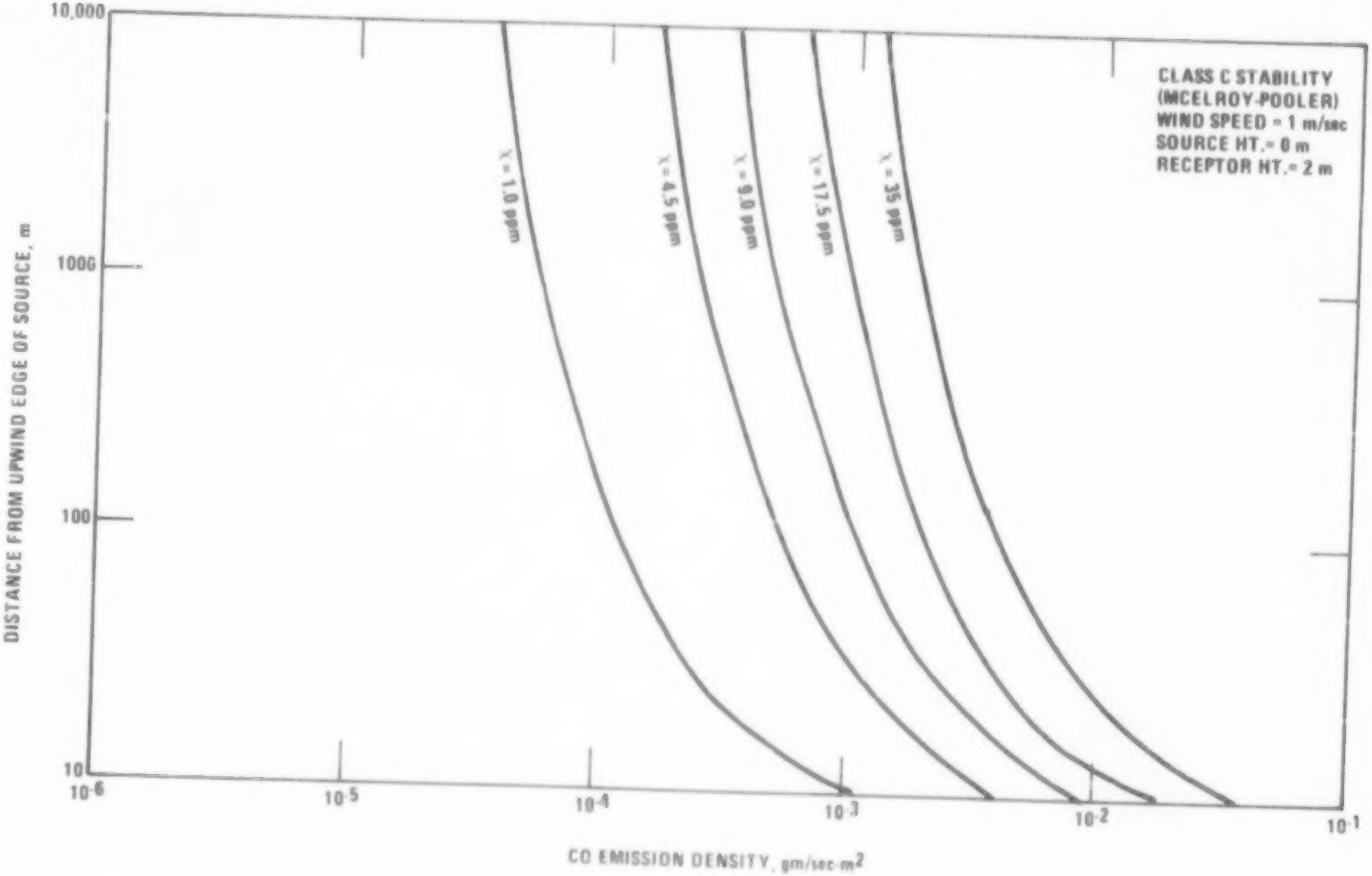


Figure H1C. Relationships among emission density, source size, and carbon monoxide concentrations.

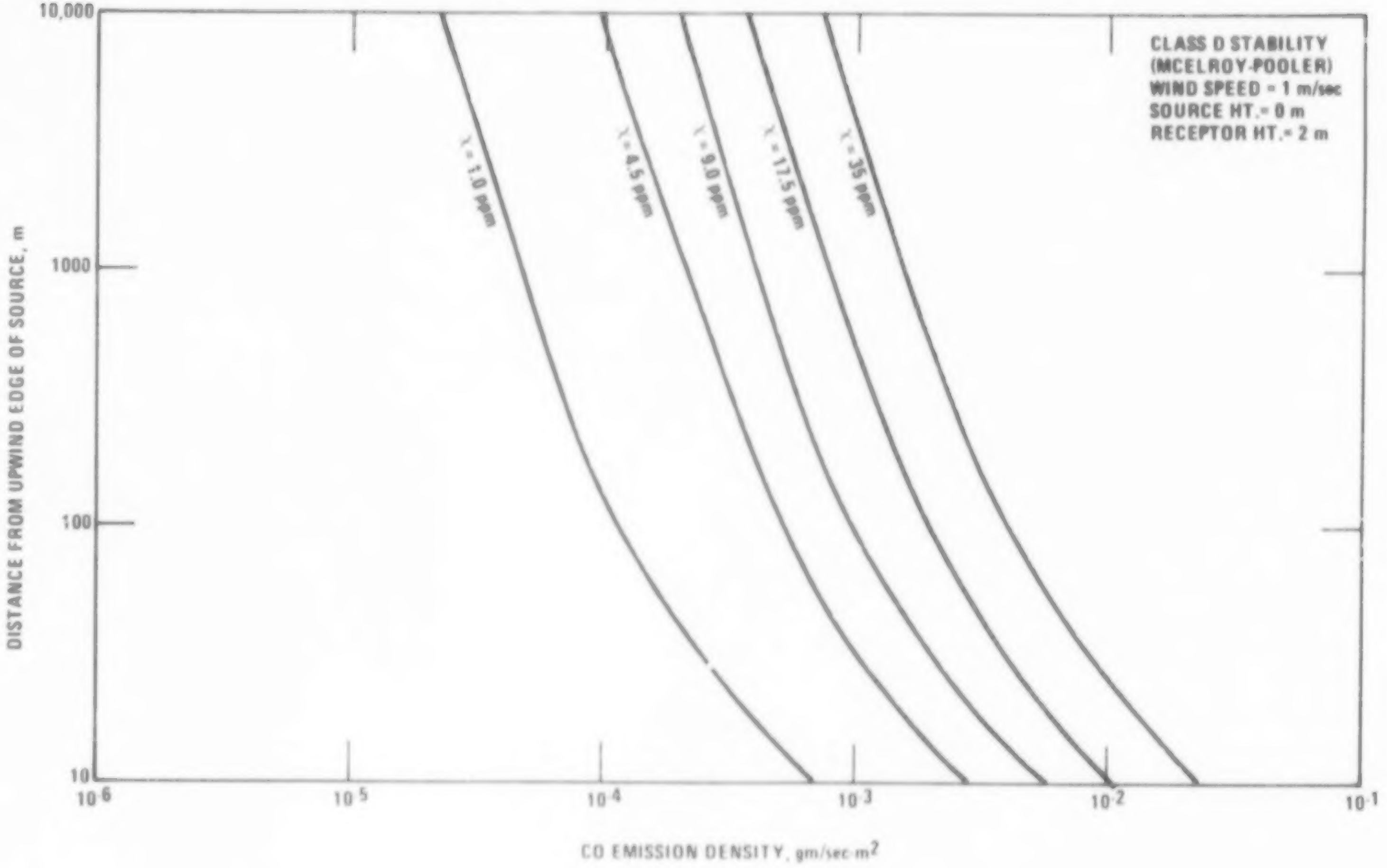


Figure H1D. Relationships among emission density, source size, and carbon monoxide concentrations.

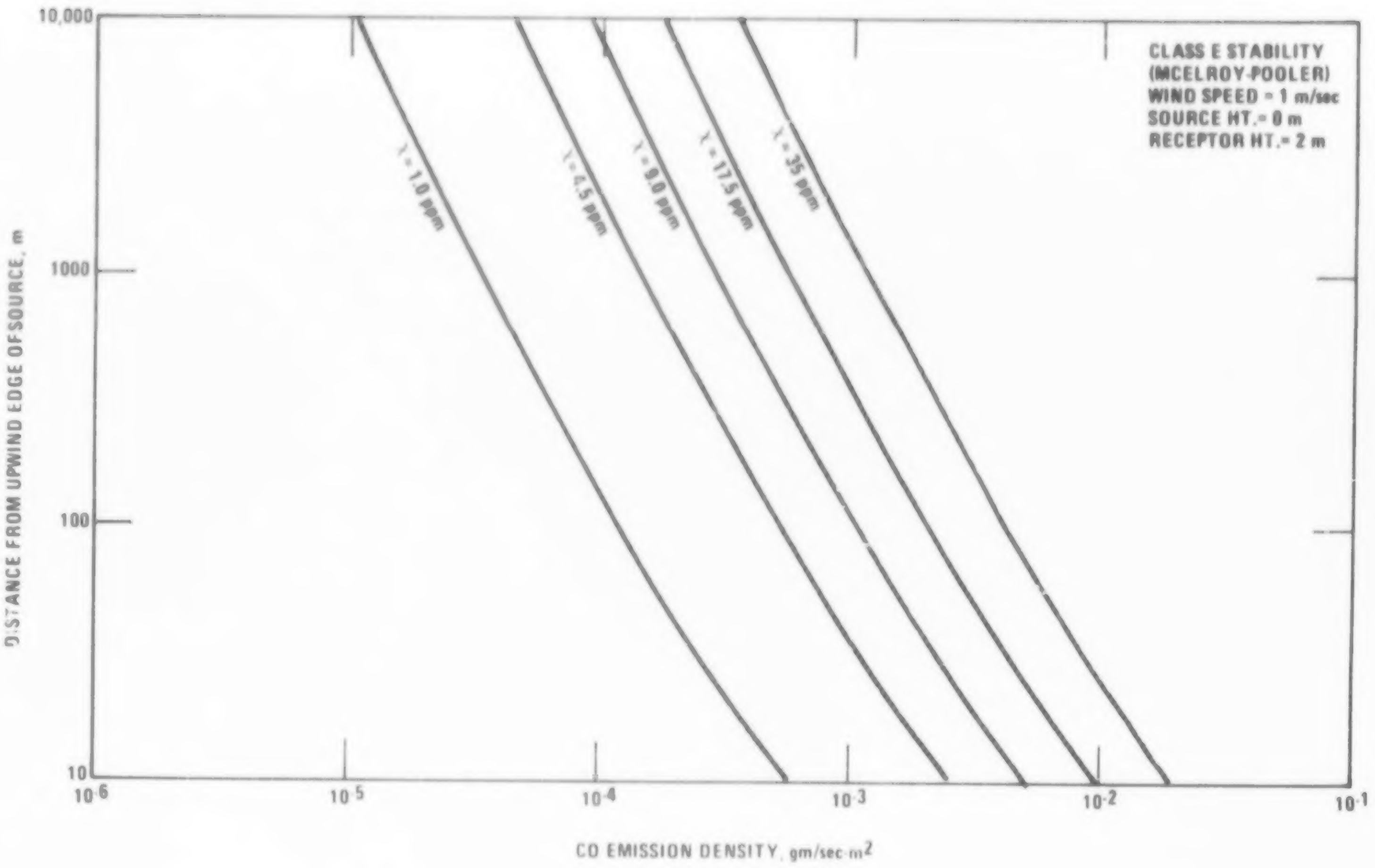


Figure H1E. Relationships among emission density, source size, and carbon monoxide concentrations.

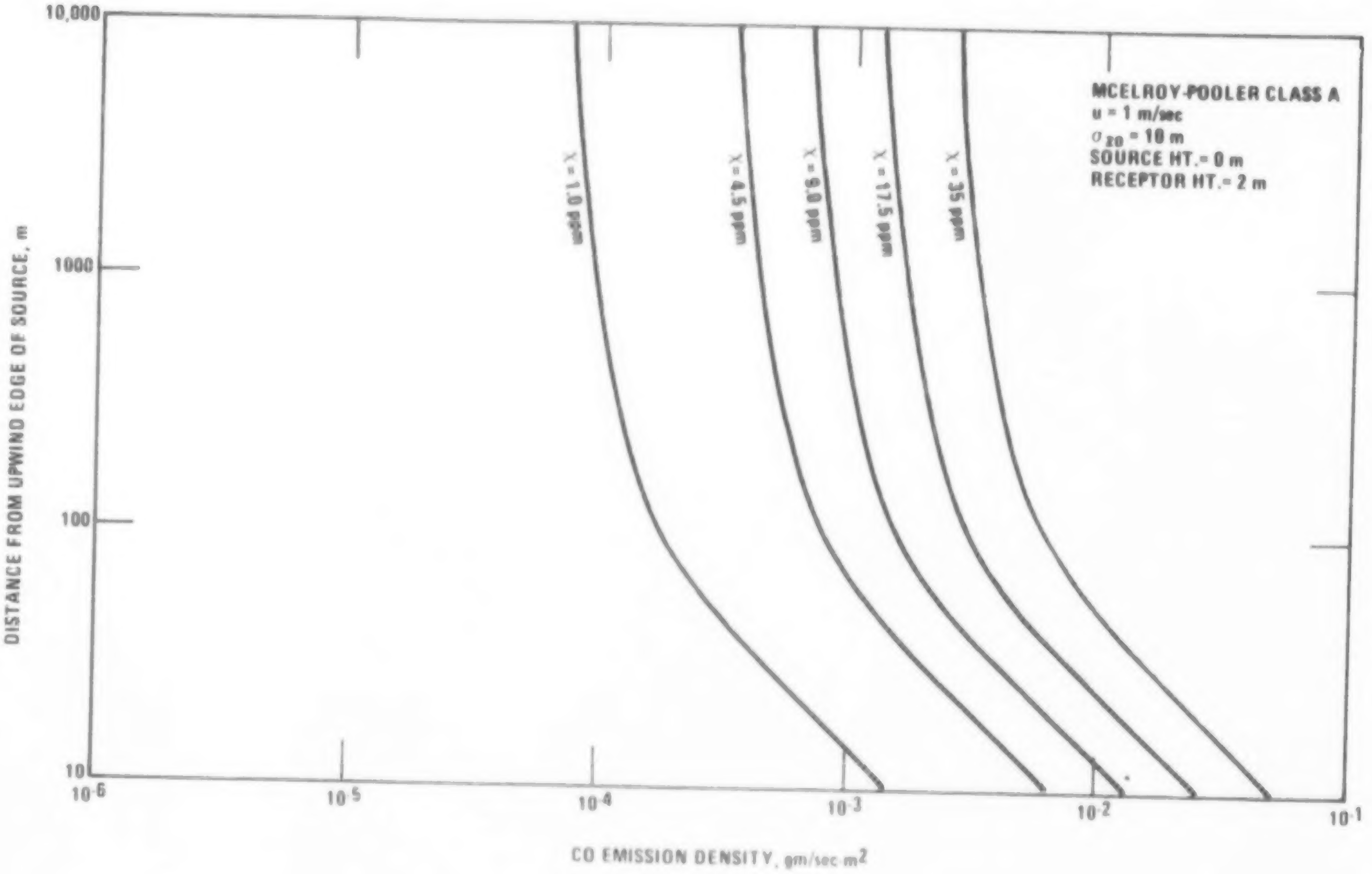


Figure H2A. Relationships among emission density, source size, and carbon monoxide concentrations.

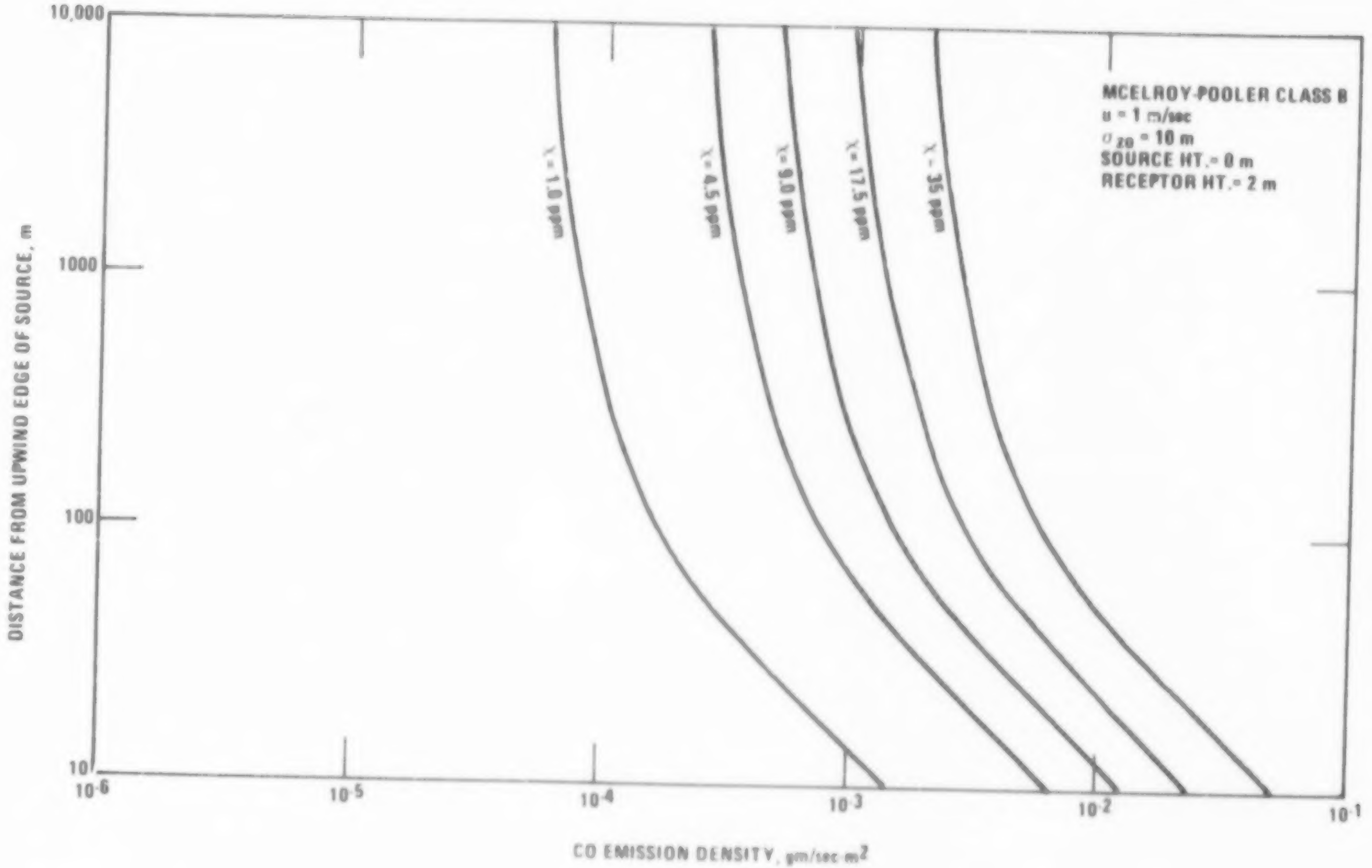


Figure H2B. Relationships among emission density, source size, and carbon monoxide concentrations.

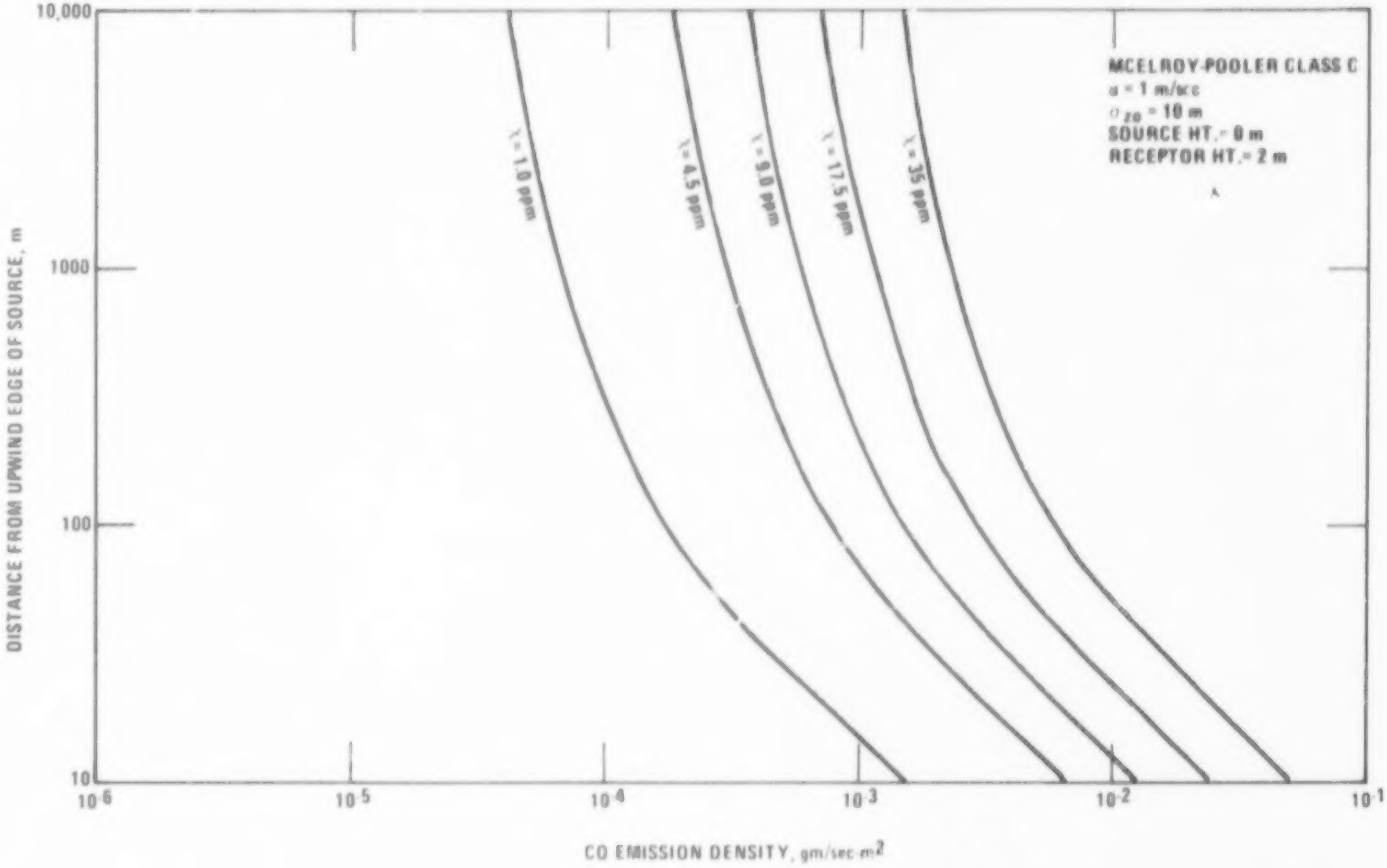


Figure H2C. Relationships among emission density, source size, and carbon monoxide concentrations.

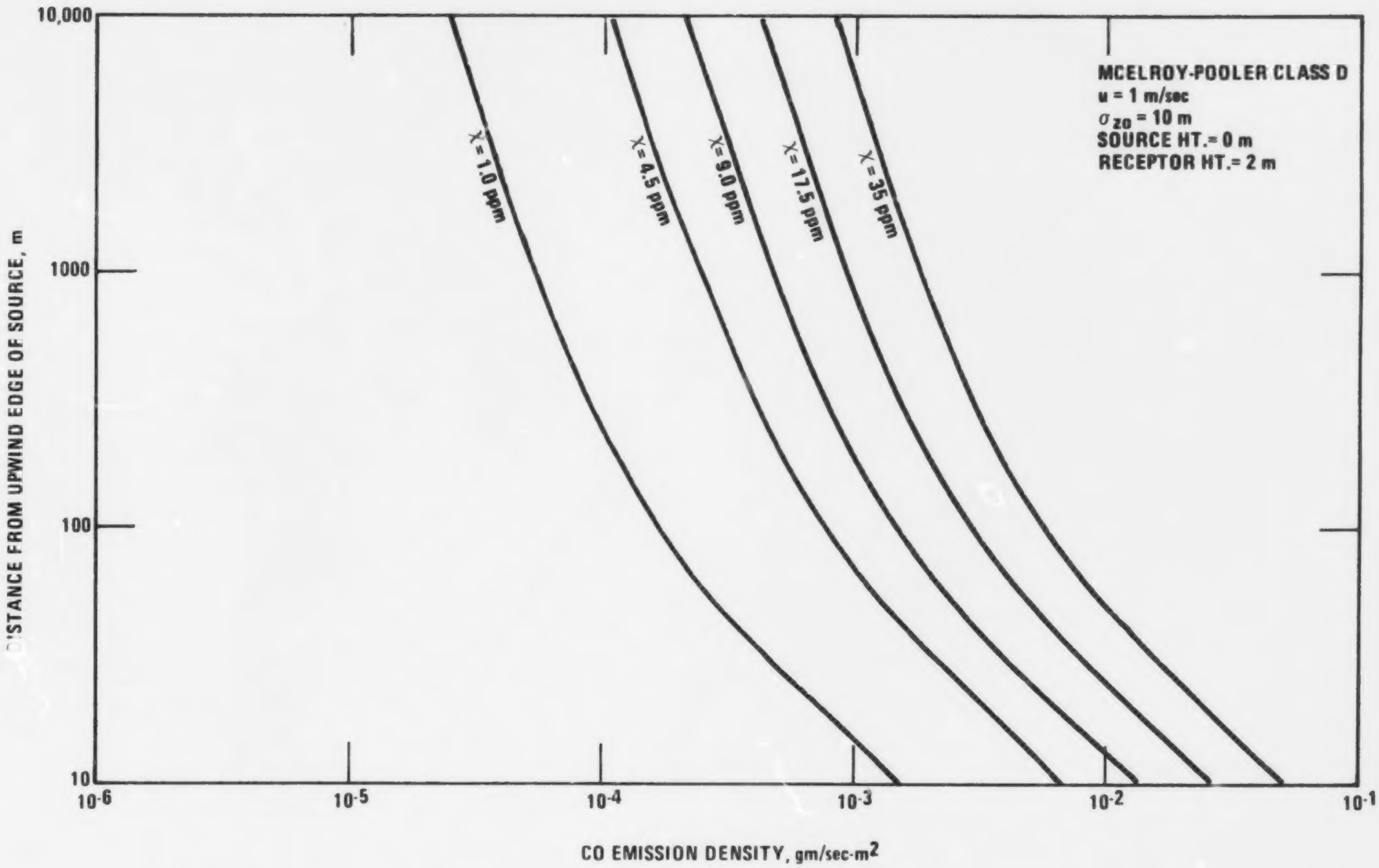


Figure H2D. Relationships among emission density, source size, and carbon monoxide concentrations.

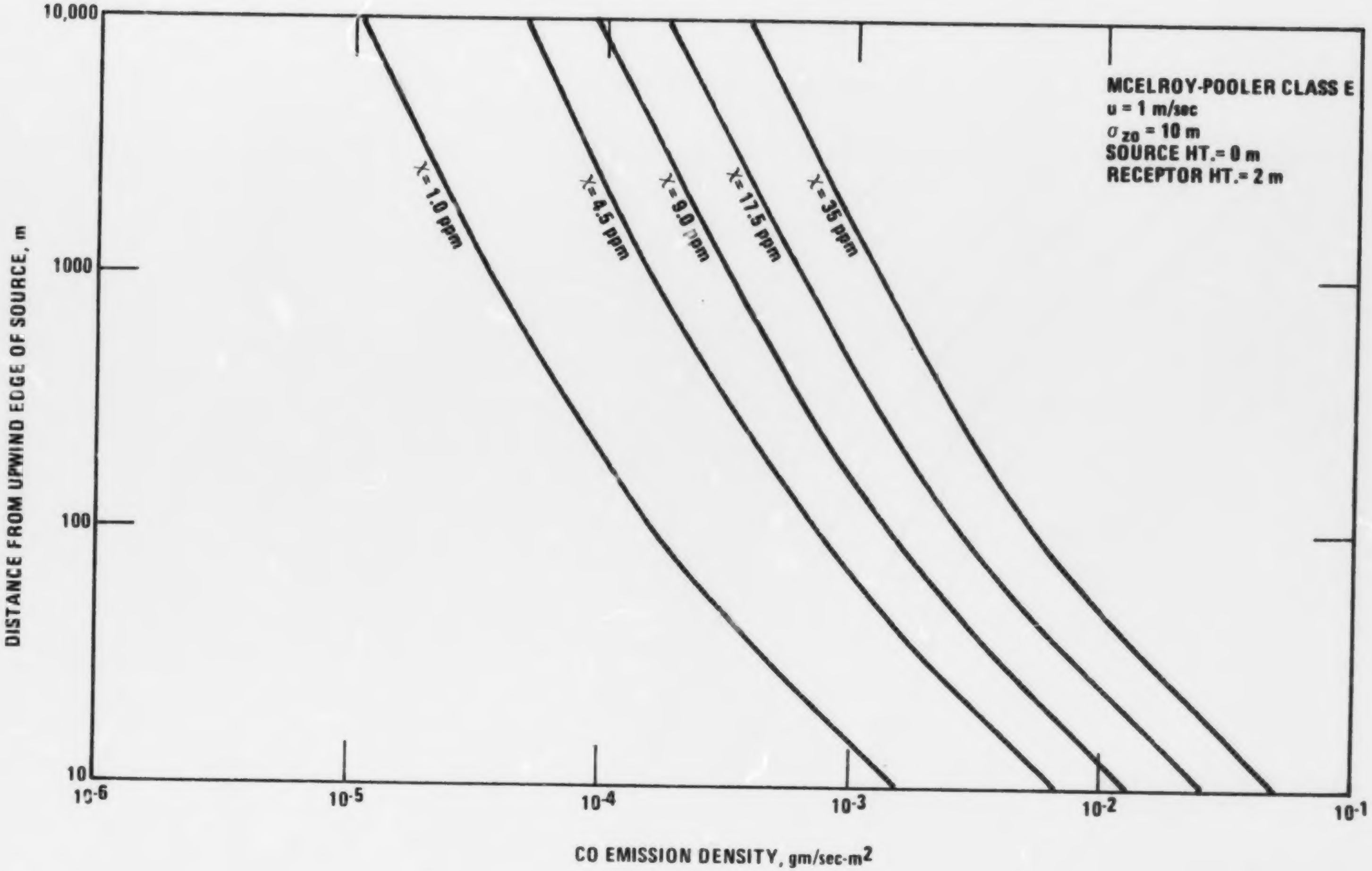


Figure H2E. Relationships among emission density, source size, and carbon monoxide concentrations.

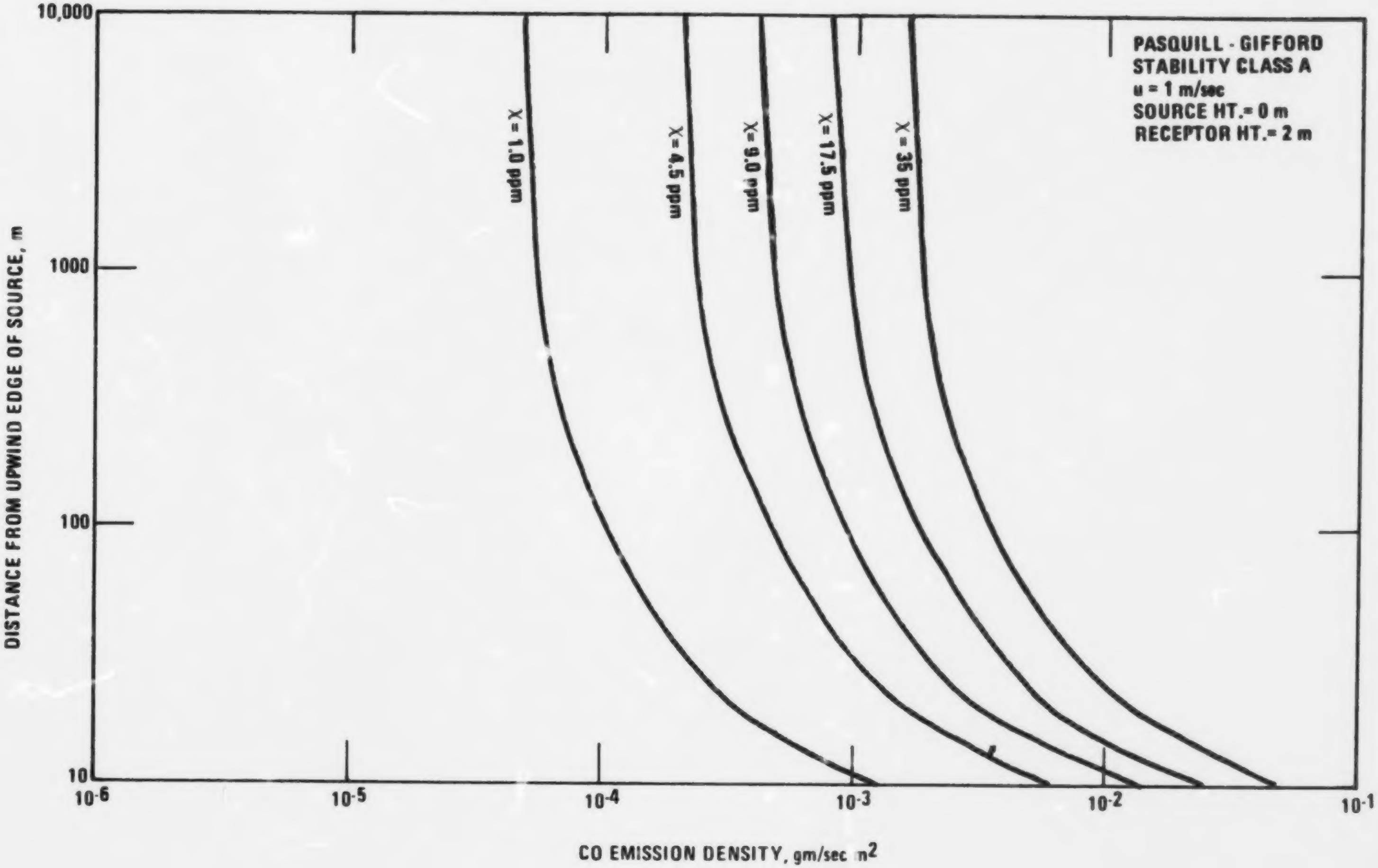


Figure H3A. Relationships among emission density, source size, and carbon monoxide concentrations.

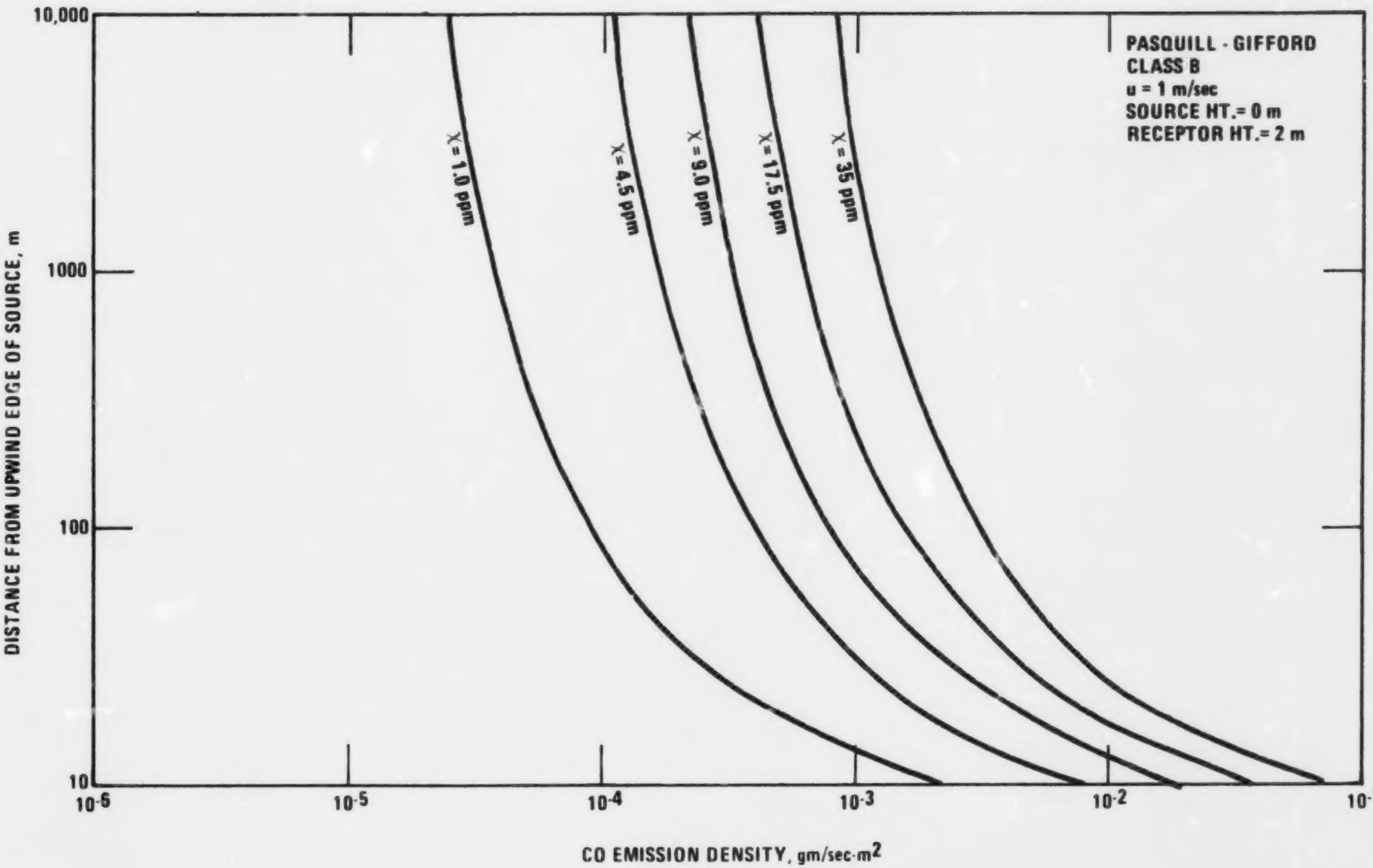


Figure H3B. Relationships among emission density, source size, and carbon monoxide concentrations.

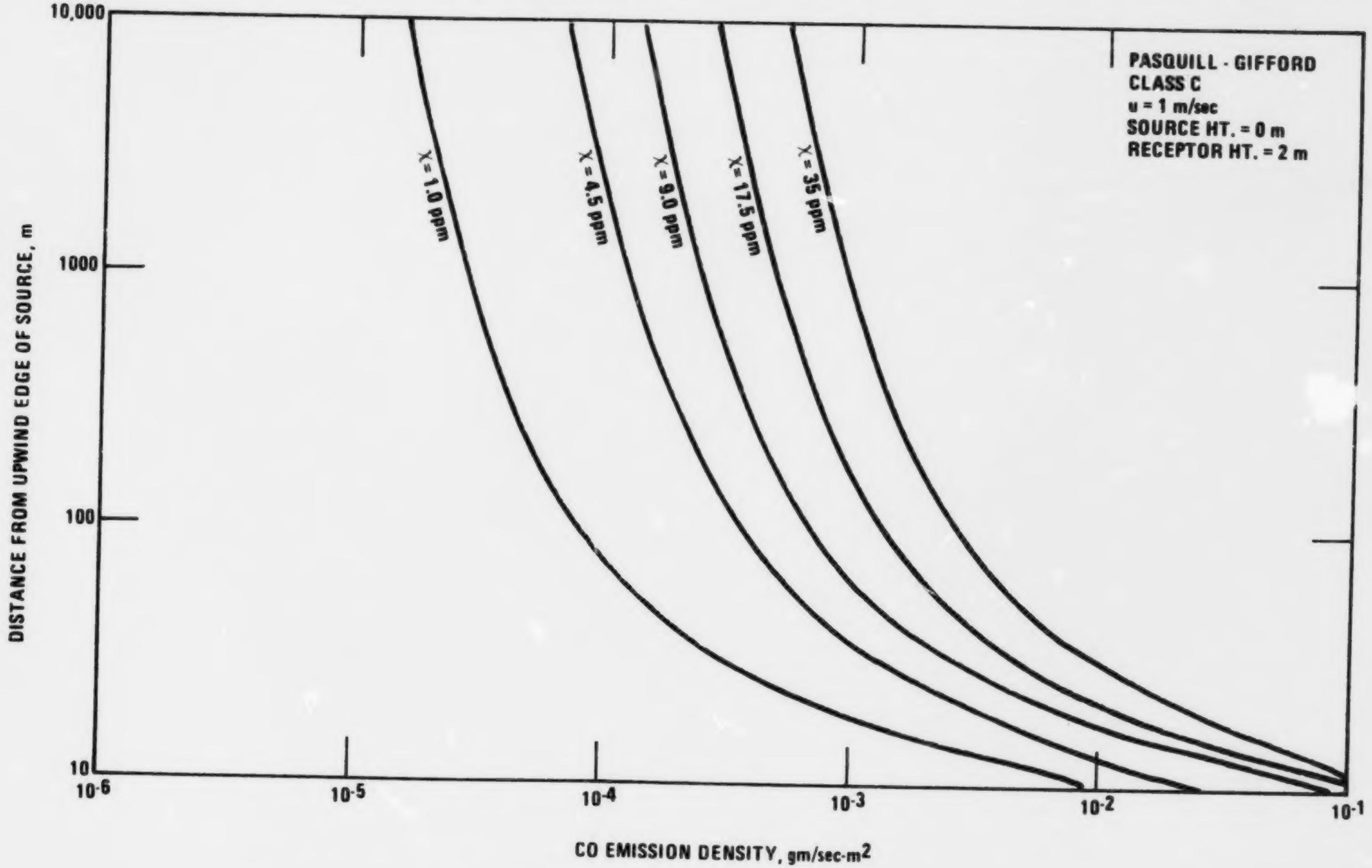


Figure H3C. Relationships among emission density, source size, and carbon monoxide concentrations.

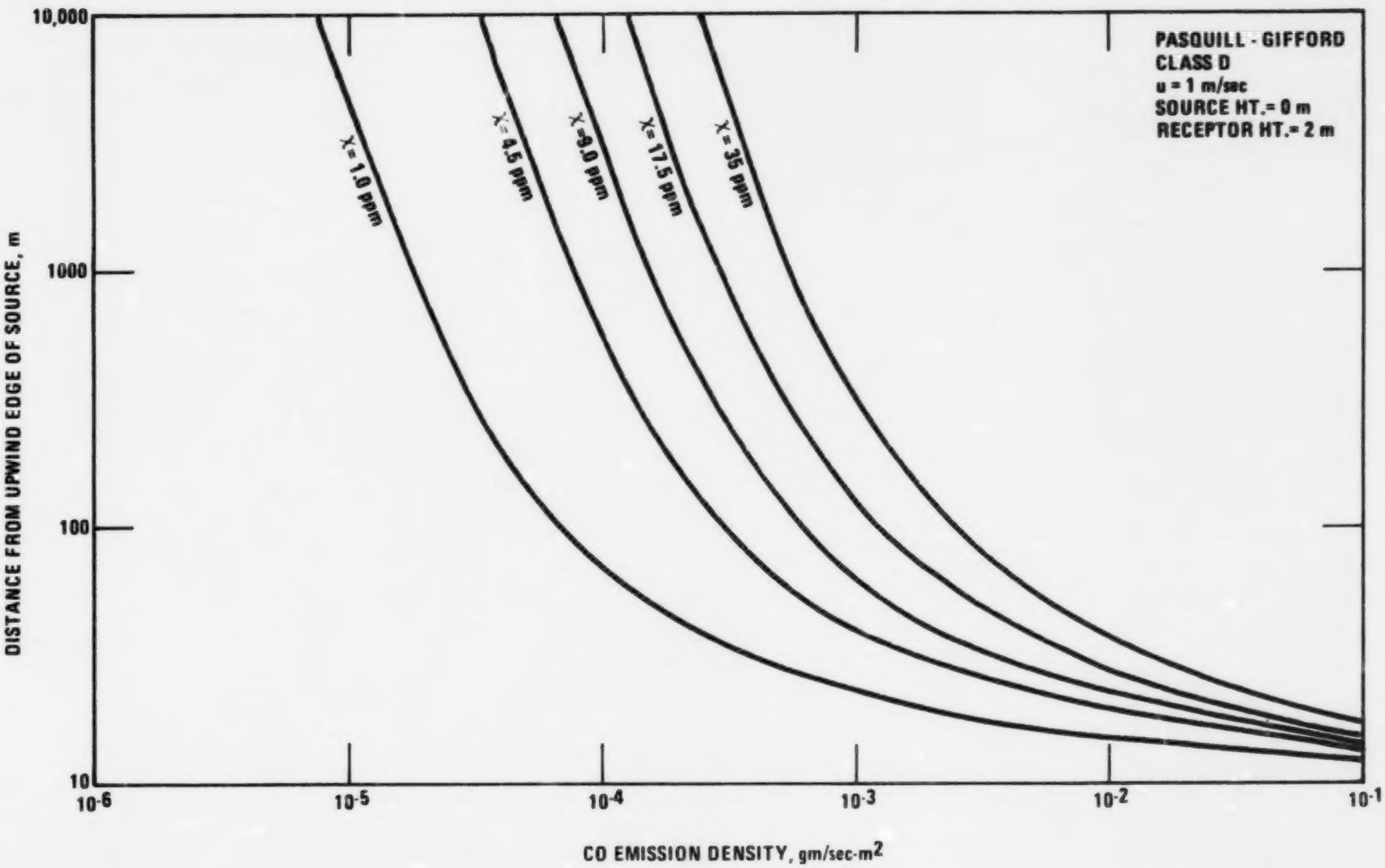


Figure H3D. Relationships among emission density, source size, and carbon monoxide concentrations.

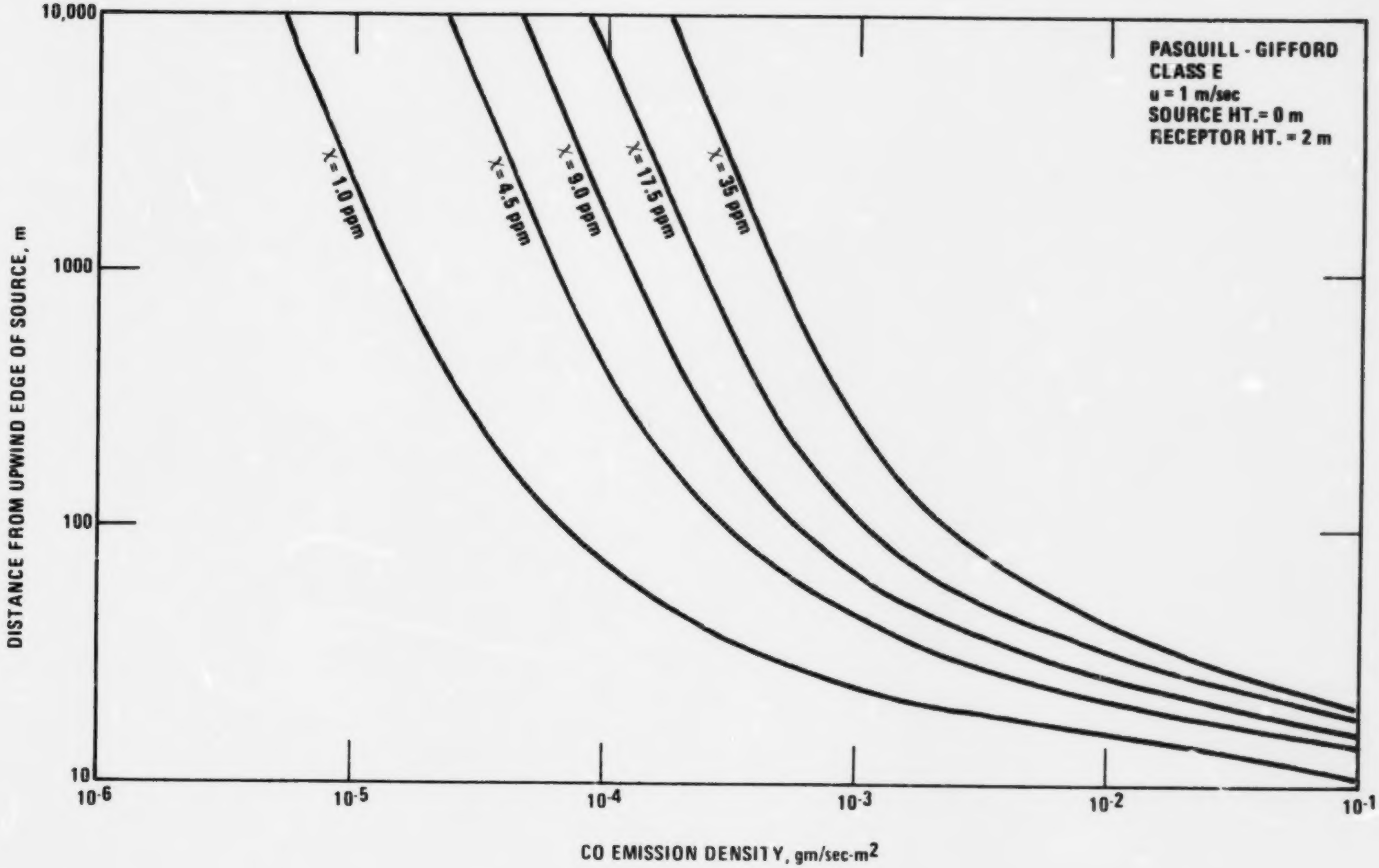


Figure H3E. Relationships among emission density, source size, and carbon monoxide concentrations.

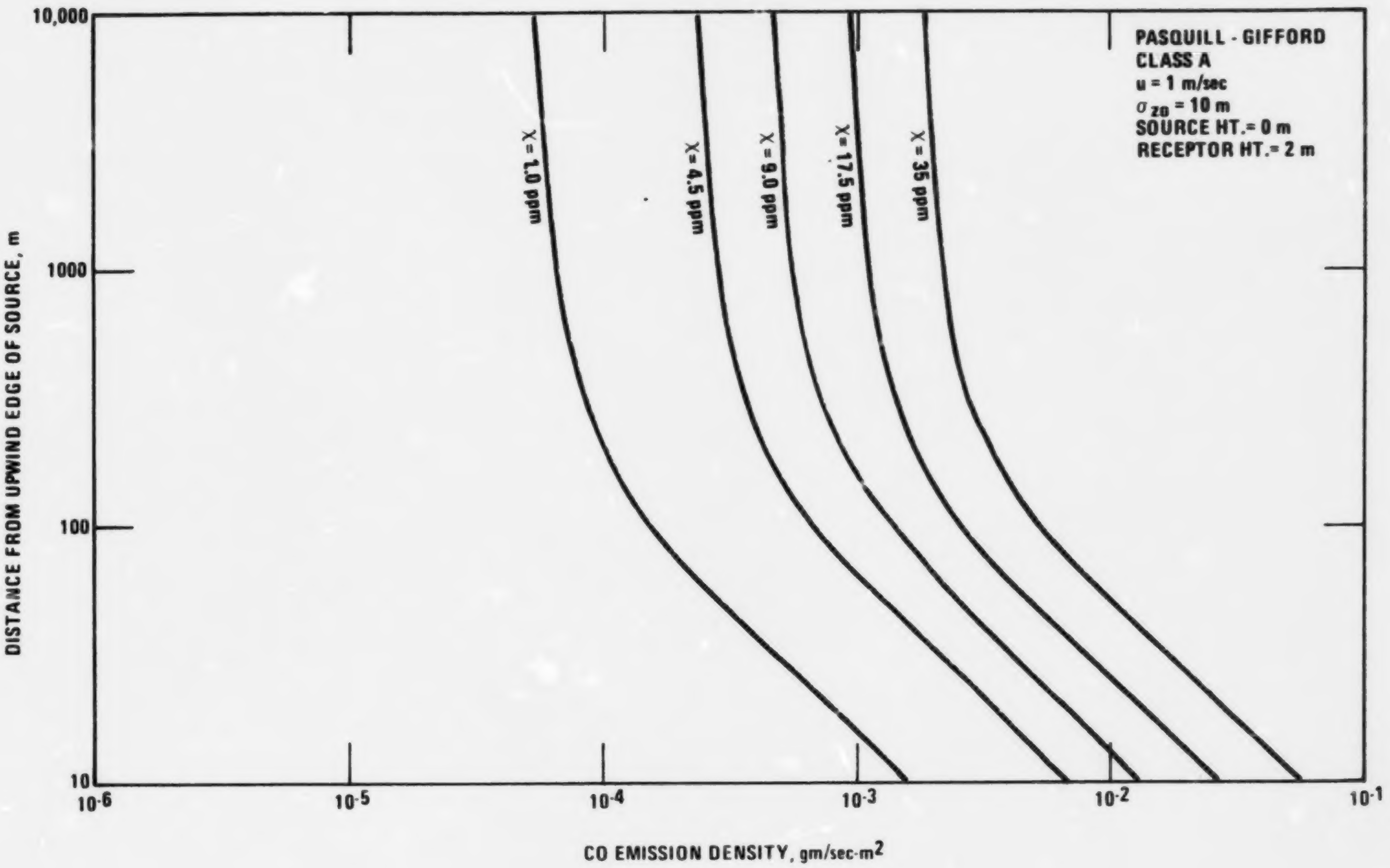


Figure **H4A**. Relationships among emission density, source size, and carbon monoxide concentrations.

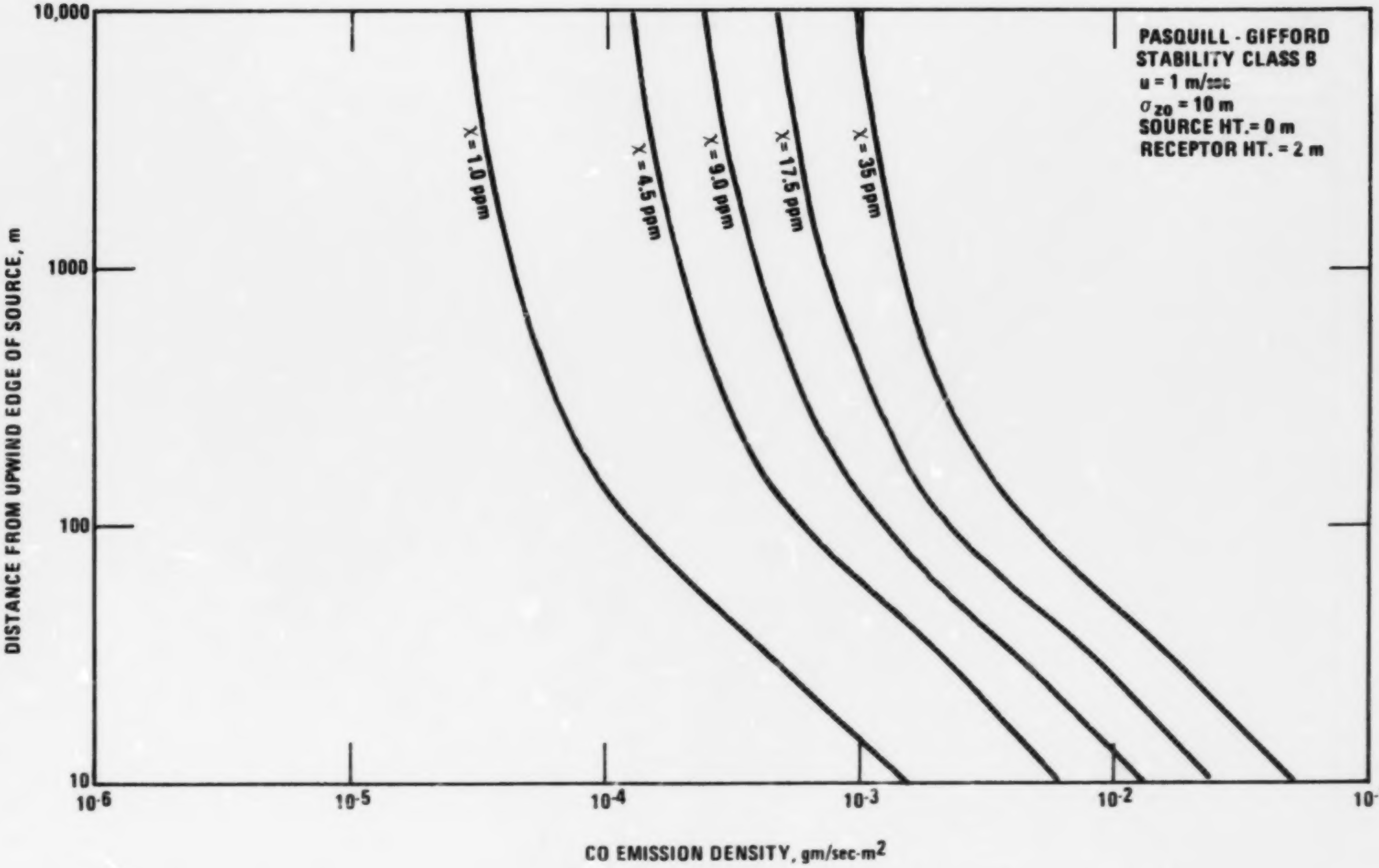


Figure H4B. Relationships among emission density, source size, and carbon monoxide concentrations.

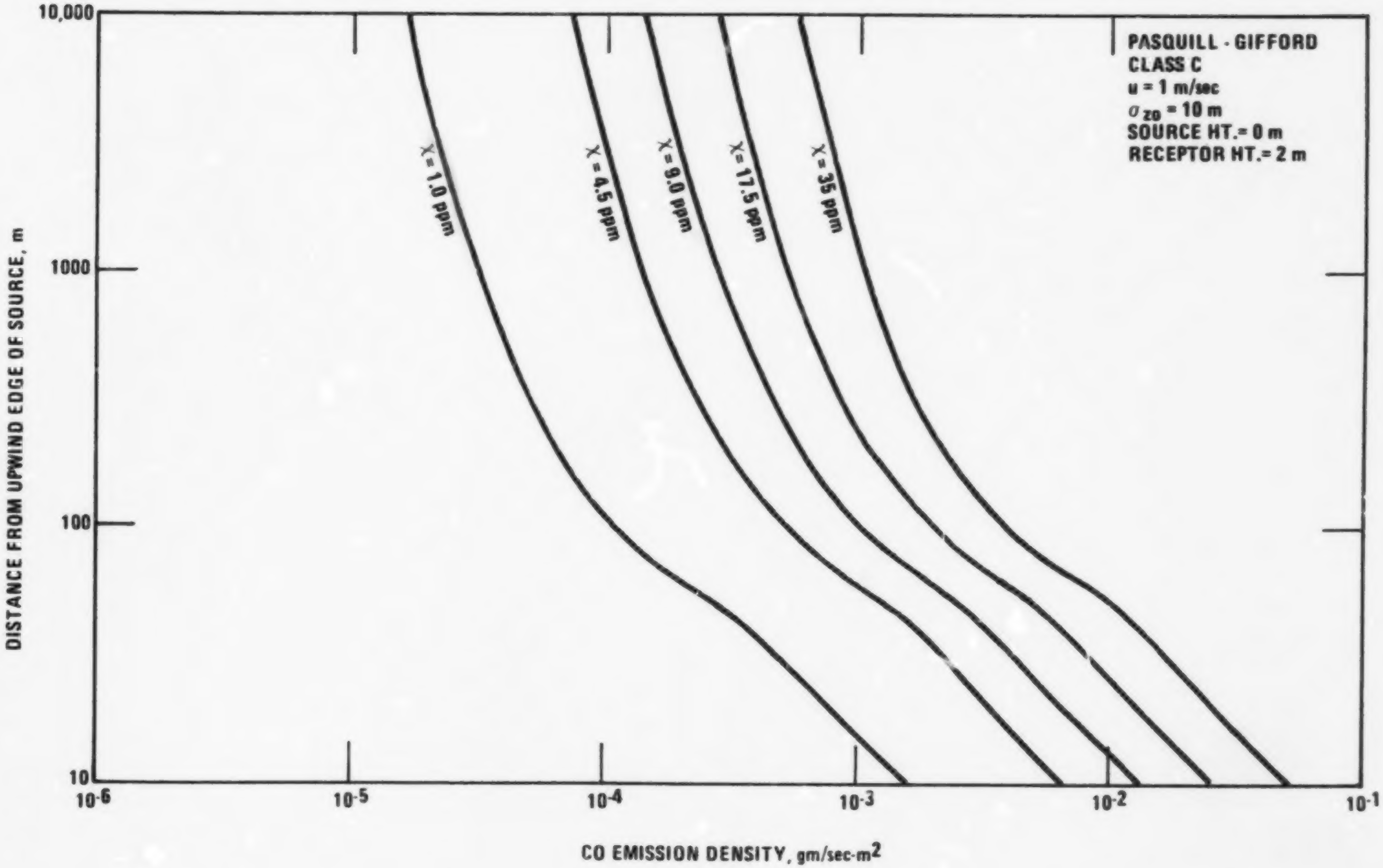


Figure H4C. Relationships among emission density, source size, and carbon monoxide concentrations.

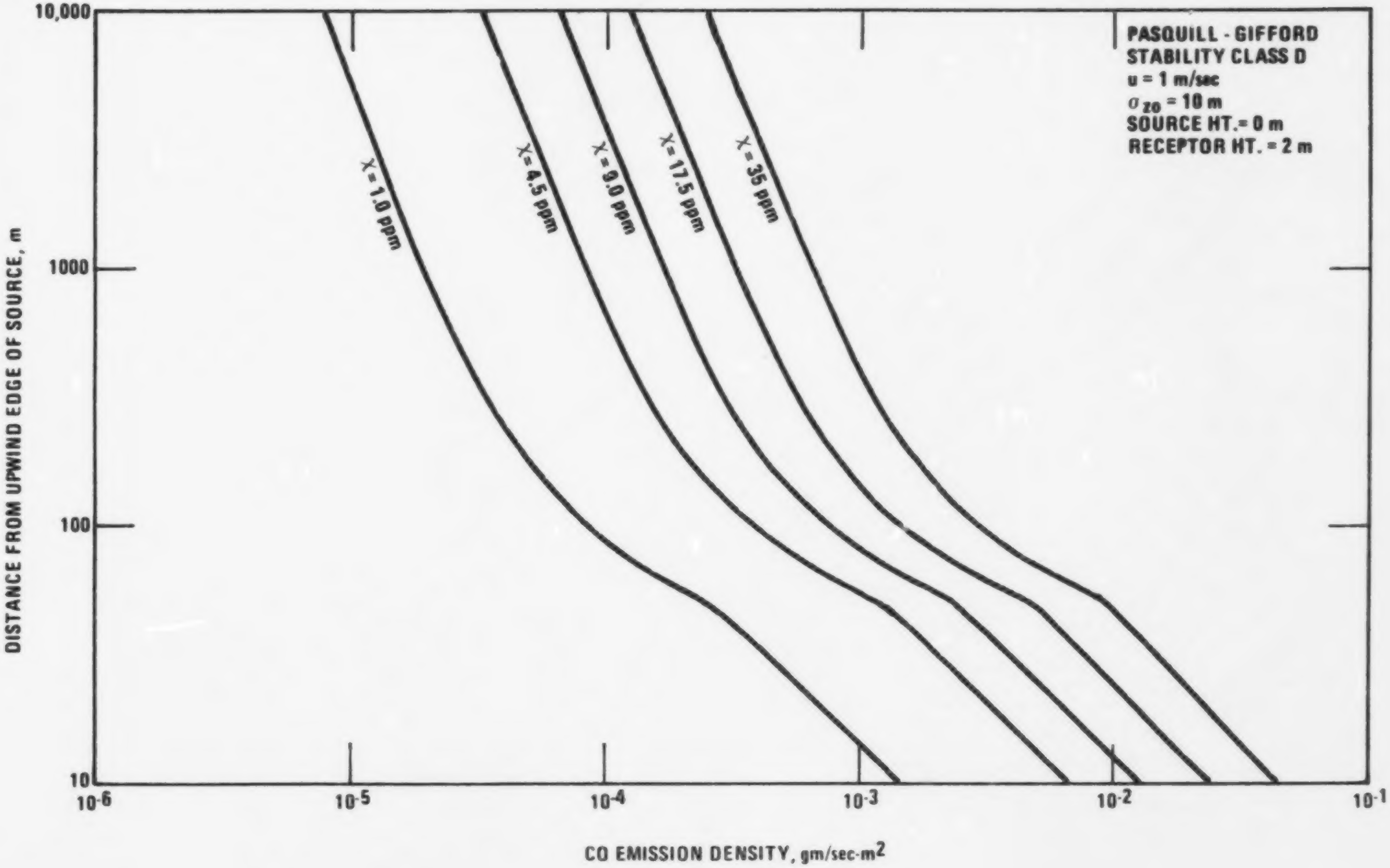


Figure H4D. Relationships among emission density, source size, and carbon monoxide concentrations.

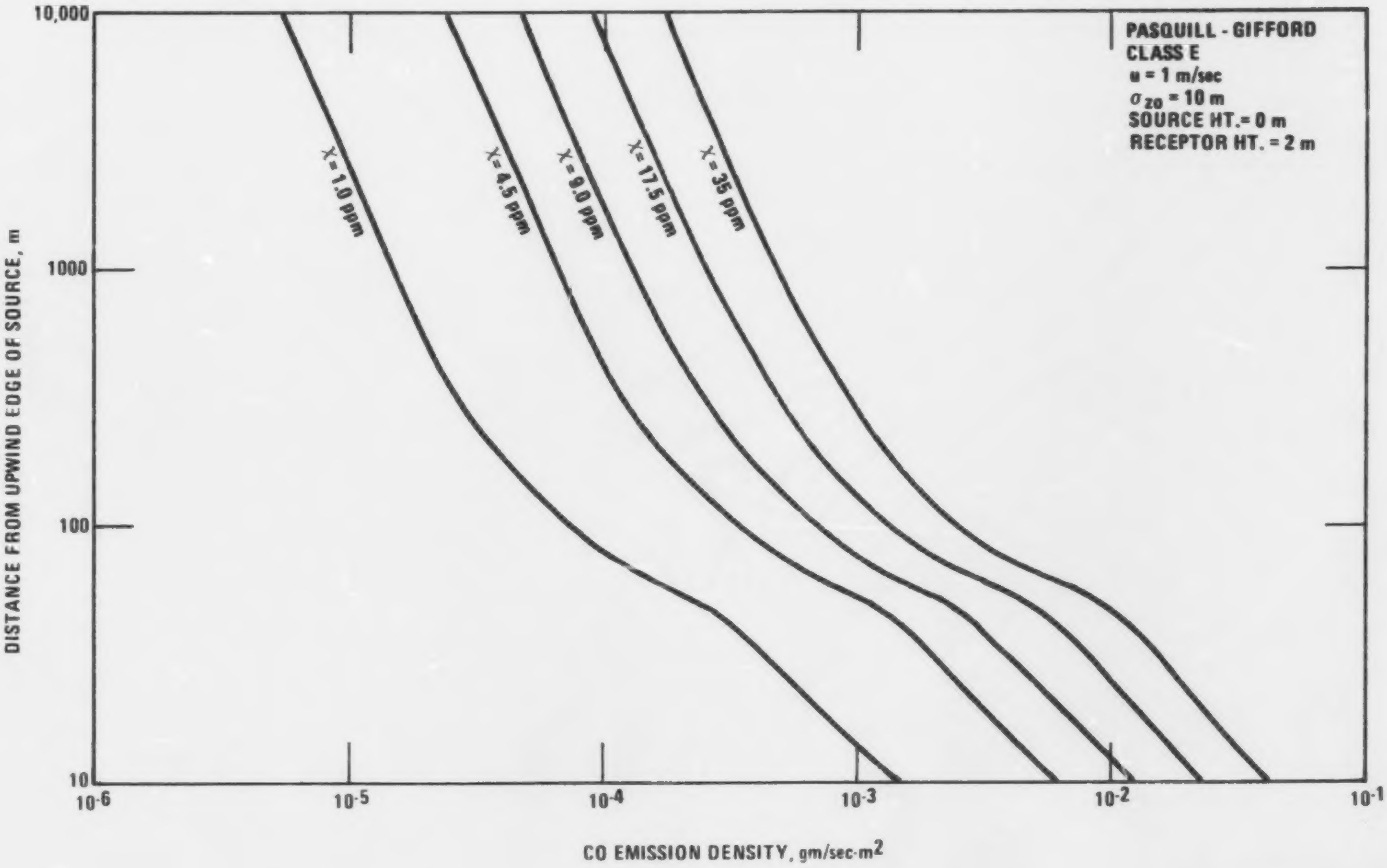


Figure H4E. Relationships among emission density, source size, and carbon monoxide concentrations.

receptor is greater than 1/2 the cross wind dimension of the source, the approach described above may overestimate the source's impact. In such cases, it may be necessary to derive emission density, source size, concentration curves based on the relationship depicted by Equation (H4) rather than Equations (H2a) - (H2c).

$$\text{f. } \frac{\chi u}{Q} = \frac{1}{\pi} \int_{0}^{x'} \frac{\exp\left[-1/2(h/ax^{b})^{2}\right]}{ax^{b}}\, dx \int_{P_1}^{P_2} \exp\left(-1/2\, P^{2}\right) dp \qquad \text{(H4)}$$

where $P_1 = Y_1/\sigma_y$ and $P_2 = Y_2/\sigma_y$

and Y_1 = crosswind distance between one side of the source and the receptor, m

Y_2 = crosswind distance between the receptor and the other side of the source, m

σ_y = lateral plume spread parameter, m

C. Impact of Nearby Traffic on 1-Hour CO Concentrations

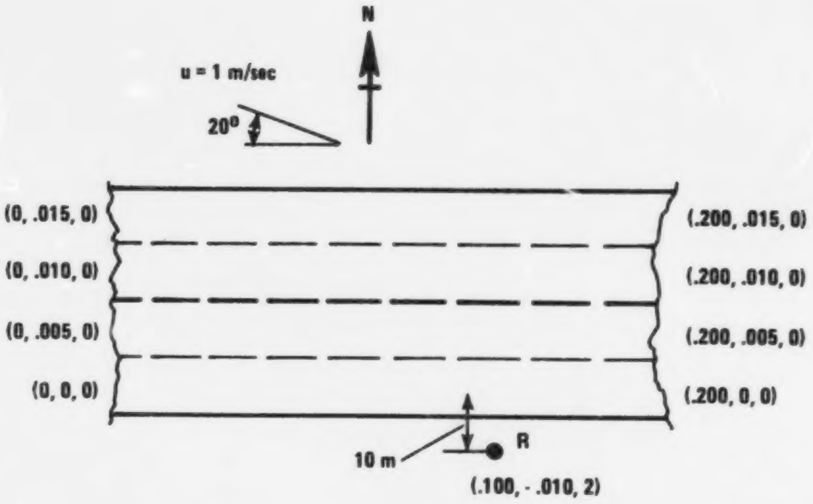
Monitoring observations in the vicinity of indirect sources have indicated that peak CO concentrations are likely to occur in the immediate vicinity of access roads or exit/entrance traffic lanes.[19,20] Such observations are substantiated by other monitoring data.[21] Such information implies a disproportionately high contribution to peak ambient CO concentrations arising from traffic in nearby (e. g., < 100m from the receptor) traffic lanes. It is suggested that a line source model be used to estimate the impact at a receptor from traffic passing nearby. As with the area source model, it is important that meteorological assumptions which are appropriate for the source site be used. Any validated line source model can be used to evaluate the effect of nearby traffic on ambient CO concentrations. The results shown in the illustrative examples described in this Appendix and elsewhere in the Guidelines were obtained using the EPA HIWAY model,[11] available on UNAMAP. Other comparable line source models could be used instead. It is not feasible to present a comprehensive series of curves accounting for all source-receptor configurations, sets of meteorological assumptions and types of roadways. Examples H2 and H3 illustrate how the HIWAY model (or some other line source model) could be applied to estimate the impact at a selected receptor point of freely flowing traffic in major traffic lanes, and the impact of traffic at an intersection with queues, respectively.

Example H2. An arterial street has 4 lanes. Each lane is 5 m wide. What is the impact of the street on 1-hour CO concentrations at a receptor located 10 m from the nearest lane at a mid-block section of the road in 1975 under the following traffic conditions?

Lane 1: $v/c = 0.6$
Lane 2: $v/c = 0.5$
Lane 3: $v/c = 0.4$
Lane 4: $v/c = 0.6$

Capacity of each lane is 1800 vph. The road is one having typical interrupted flow with uncoordinated signals and a 25 mph speed limit. The following meteorological conditions prevail: Pasquill-Gifford Class D atmospheric stability with the mean hourly wind speed of 1 m/sec making an angle of 20° with the road's centerline

SOLUTION


N
u = 1 m/sec
20°
(0, .015, 0)
(0, .010, 0)
(0, .005, 0)
(0, 0, 0)
(.200, .015, 0)
(.200, .010, 0)
(.200, .005, 0)
(.200, 0, 0)
10 m
R
(.100, - .010, 2)

The coordinates of the source and receptor for use in the HIWAY model are pictured above. Using Figure A5 (Appendix A), vehicle speed ~ 20 mph for each lane. Since the traffic is freely flowing at mid-block, emission intensities can be estimated using Equation (A11) and Figure A6.

For lane 1, $q = (1.036 \times 10^{-5})(18.0)(1080)/20 = .0100$ gm/sec-m

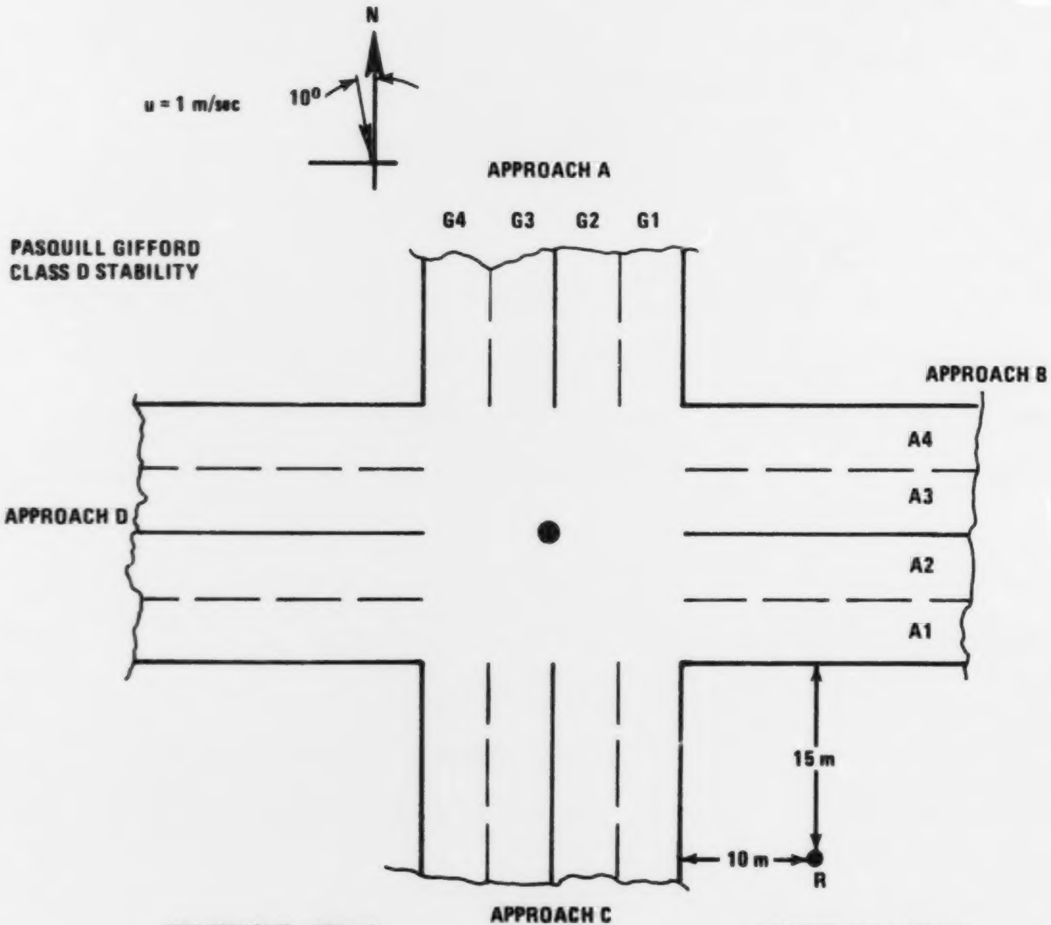
For lane 2, $q = (1.036 \times 10^{-5})(18.0)(900)/20 = .0084$ gm/sec-m

For lane 3, $q = (1.036 \times 10^{-5})(18.0)(720)/20 = .0067$ gm/sec-m

For lane 4, $q = (1.036 \times 10^{-5})(18.0)(1080)/20 = .0100$ gm/sec-m

Using the above information in HIWAY, the estimated impact at R is 16 ppm.

Example H3. A four-legged intersection of two 4-laned arterial streets is as shown. For approaches A and C, G/C_y = 0.6. For approaches B and D, G/C_y = 0.3 (the amber phase is assumed to occur 10 percent of the time). Signal cycle length is 100 seconds. Assume, for illustrative purposes, that the approach speed to all approaches is 25 mph. A receptor site R is located as shown. Each lane is 5 m wide.


N
u = 1 m/sec
10°
APPROACH A
G4
G3
G2
G1
PASQUILL GIFFORD
CLASS D STABILITY
APPROACH B
A4
A3
A2
A1
APPROACH D
15 m
10 m
R
APPROACH C

VOLUME (G4) = 800 vph
VOLUME (G3) = 800 vph
VOLUME (G2) = 600 vph
VOLUME (G1) = 600 vph

VOLUME (A4) = 400 vph
VOLUME (A3) = 400 vph
VOLUME (A2) = 300 vph
VOLUME (A1) = 300 vph

Solution: The solution to this problem is obtained using an approach which has been used successfully for an at-grade intersection near a regional shopping center.[22]

Proceed by using Table A10 (Appendix A).

Lane G4: q_1 = .0116 gm/sec-m over a queue length of 71 meters.
q_2 = .0057 gm/sec-m elsewhere.
Lane G3: q_3 = .0116 gm/sec-m over a queue length of 71 meters.
q_4 = .0057 gm/sec-m elsewhere.
Lane G2: q_5 = .0110 gm/sec-m over a queue length of 53 meters.
q_6 = .0043 gm/sec-m elsewhere.
Lane G1: q_7 = .0110 gm/sec-m over a queue length of 53 meters.
q_8 = .0043 gm/sec-m elsewhere.
Lane A4: q_9 = .0161 gm/sec-m over a queue length of 62 meters.
q_{10} = .0029 gm/sec-m elsewhere.
Lane A3: q_{11} = .0161 gm/sec-m over a queue length of 62 meters.
q_{12} = .0029 gm/sec-m elsewhere.
Lane A2: q_{13} = .0152 gm/sec-m over a queue length of 47 meters.
q_{14} = .0022 gm/sec-m elsewhere.
Lane A1: q_{15} = .0152 gm/sec-m over a queue length of 47 meters.
q_{16} = .0022 gm/sec-m elsewhere.

Redrawing the intersection and receptor as a source and receptor site suitable for input in HIWAY, one obtains the following. Source and receptor data are contained in Table H2.

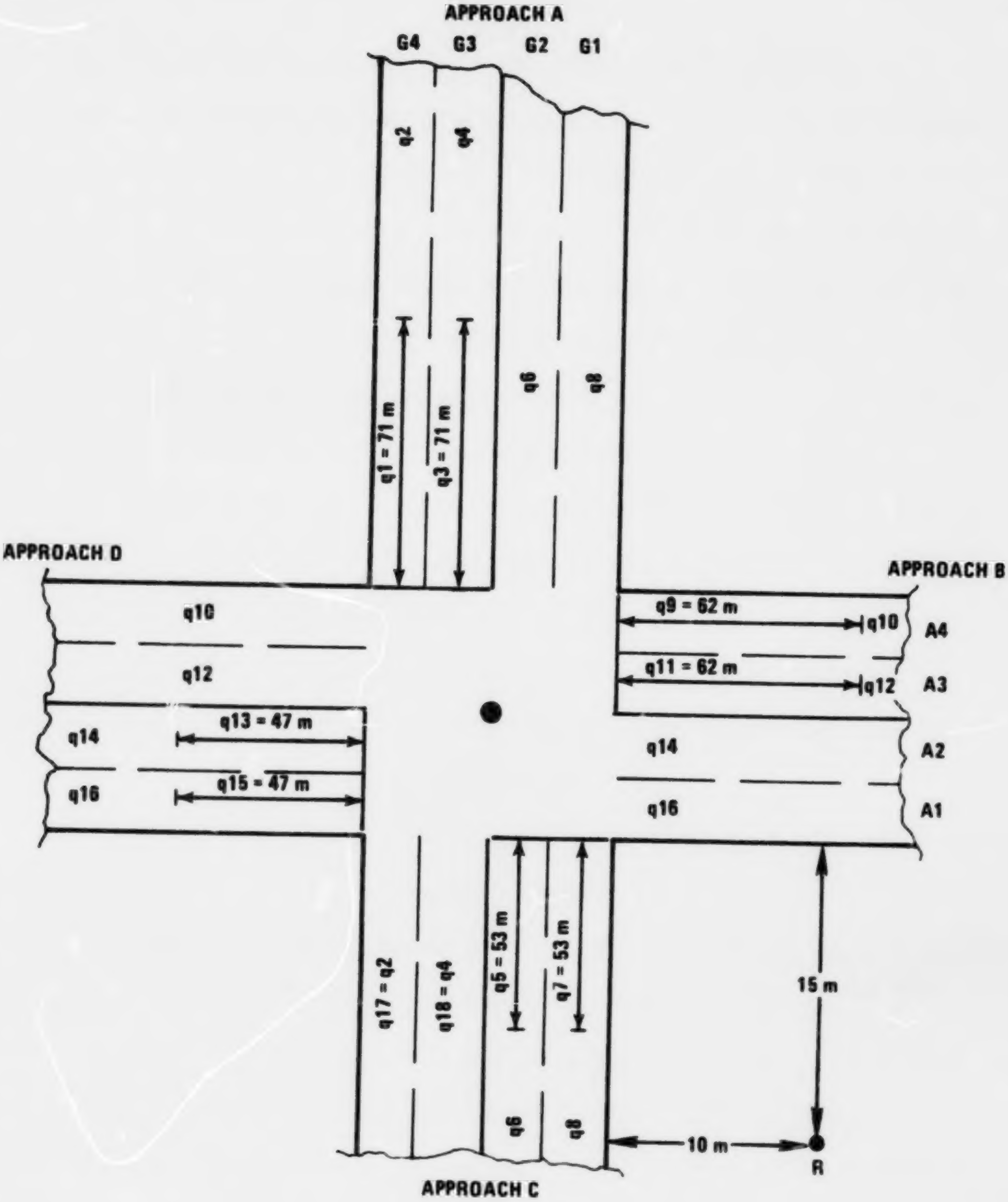

APPROACH A
G4
G3
G2
G1
q2
q4
q1 = 71 m
q3 = 71 m
q6
q8
APPROACH D
q10
q12
q14
q16
q13 = 47 m
q15 = 47 m
APPROACH B
q9 = 62 m
q10
A4
q11 = 62 m
q12
A3
q14
A2
q16
A1
q17 = q2
q18 = q4
q5 = 53 m
q7 = 53 m
q6
q8
15 m
10 m
R
APPROACH C

Table H2. INPUT INFORMATION FOR EXAMPLE H3

Source Designation	West* Coordinates	East* Coordinates	North* Coordinates	South* Coordinates	Emission Intensity (gm/sec-m)
q_1	-	-	(.152,.091,0)	(.152,.020,0)	.0116
q_2	-	-	(.152,.191.0)	(.152,.191,0)	.0057
q_3	-	-	(.157,.091,0)	(.157,.020,0)	.0116
q_4	-	-	(.157,.191,0)	(.157,.091,0)	.0057
q_5	-	-	(.162, 0, 0)	(.162,-.053,0)	.0110
q_6	-	-	(.162,.191,0)	(.162, 0, 0)	.0043
q_7	-	-	(.167, 0, 0)	(.167,-.053,0)	.0110
q_8	-	-	(.167,.191,0)	(.167, 0, 0)	.0043
q_9	(.167,.015,0)	(.229,.015,0)	-	-	.0161
q_{10}	(.100,.015,0)	(.167,.015,0)	-	-	.0029
q_{11}	(.167,.010,0)	(.229,.010,0)	-	-	.0161
q_{12}	(.100,.010,0)	(.167,.010,0)	-	-	.0029
q_{13}	(.100,.005,0)	(.147,.005,0)	-	-	.0152
q_{14}	(.147,.005,0)	(.229,.005,0)	-	-	.0022
q_{15}	(.100, 0, 0)	(.147, 0, 0)	-	-	.0152
q_{16}	(.147, 0, 0)	(.229, 0, 0)	-	-	.0022
q_{17}	-	-	(.152,.020,0)	(.152,-.053,0)	.0057
q_{18}	-	-	(.157,.020,0)	(.157,-.053,0)	.0057

Receptor Site Coordinates* are (.1795,-.0175,2)

*Coordinates are expressed in (km, km, m).

Entering the preceding information as input data to HIWAY, one obtains:

$\chi_{q1} = 0.9$ ppm

$\chi_{q2} = 1.2$ ppm

$\chi_{q3} = 1.8$ ppm

$\chi_{q4} = 1.3$ ppm

$\chi_{q5} = 0$ ppm

$\chi_{q6} = 2.1$ ppm

$\chi_{q7} = 0$ ppm

$\chi_{q8} = 2.6$ ppm

$\chi_{q9} = 2.8$ ppm

$\chi_{q10} = 0.1$ ppm

$\chi_{q11} = 3.0$ ppm

$\chi_{q12} = 0$ ppm

$\chi_{q13} = 0$ ppm

$\chi_{q14} = 0.5$ ppm

$\chi_{q15} = 0$ ppm

$\chi_{q16} = 0.5$ ppm

$\chi_{q17} = 0$ ppm

$\chi_{q18} = 0$ ppm

Total = χ = 16.8 ~ 17 ppm

Note in Example H3 that the end points of the "infinite" line sources attributable to cruising vehicles have been selected so that the source is long enough to make edge effects negligible with the given source-receptor configuration.

Peak concentrations at a receptor site located near traffic lanes and near a parking lot are estimated by adding the estimates obtained with an area source model (depicting the parking lot), a line source model (for traffic in nearby traffic lanes) and superimposing these estimates over the general background concentrations. This procedure is illustrated in Example H4 for receptors R1 and R2 near the indirect source in the accompanying illustration. Two other types of receptors may be of interest as well. Receptor R3 is located within the parking lot but not near any major traffic lanes. Estimates at such sites may be obtained by superimposing area source model estimates upon general background concentrations, as shown in Example H4. The fourth type of receptor is located near major traffic lanes but not influenced by traffic in the parking lot. Receptor R4 is an example of such a site. CO concentrations at sites like R4 may be estimated by superimposing the results of a line source model on general background concentrations.

Example H4. Suppose it is of interest to estimate 1-hour CO concentrations at four receptor sites shown in the accompanying sketch of a proposed indirect source in 1975. Assume that no emission correction factors for percent cold starts, altitudes, etc. are needed.

(a) Receptor R1: Located in the vicinity of the intersection of the parking lot's major exit/entrance and the access road to this exit/entrance;

(b) Receptor R2: Located downwind from the source's parking lot and a section of the access road which is too far from an intersection to be influenced appreciably by the intersection;

(c) Receptor R3: Located within the parking lot, but not within 100 meters of any major traffic lane or entrance/exit lane; and

(d) Receptor R4: Located downwind from the access road, but in a position which would not be influenced by traffic in the proposed parking lot.

The critical meteorological conditions are assumed to be as shown on the sketch. Estimate ambient 1-hour CO concentrations at Receptors R1, R2, R3 and R4 under the assumed conditions.

Solution

(1) Estimate background concentrations.

For the sake of illustration, assume that background levels are to be estimated using hourly CO readings obtained for two weeks at a representative site near the proposed source and from a year's worth of CO data obtained at a historical monitoring site. Further, suppose that using methods similar to those in Example 5 (Section 4.6 of the Guidelines), a 1-hour background concentration of 6 ppm is obtained.

(2) Use source operating and design information to estimate the emission density at the parking lot.

Using methods described in Appendices B-G, or some other suitable means, suppose the emission density of the lot is determined to be 1.0×10^{-5} gm/sec-m^2.

(3) Use traffic and design information for the entrance/exit and access road to estimate queue lengths at the intersection approaches and the line source emission intensities at the queues and elsewhere.

Methods described in the microanalysis portion of Appendix A may be used to perform this step. Suppose the end result of this analysis is as shown in the sketch (Figure H8) accompanying this example. Record this information in a form suitable for use in a line source model. This is done in Table H3 for use in the EPA HIWAY model. It is now possible to use the information derived in these first three steps to estimate ambient 1-hour CO concentrations at R1, R2, R3 and R4.

(4) Consider R1

$x_{R1} = x_b + x_A + x_1$

(a) x_b = 6 ppm

(b) Using Equation (H3) and Figure H3D,

$$x_A = (1)\left[\frac{1.0 \times 10^{-4}}{2 \times 10^{-5}}\right]_{730} - (1)\left[\frac{1.0 \times 10^{-4}}{4.4 \times 10^{-4}}\right]_{30} \qquad \text{(H3)}$$

x_A = 4.8 ppm

(c) Referring to Table H4, x_1 = 27.3 ppm

(d) Therefore,

$x_{R1} = 6 + 4.8 + 27.3 = 38.1 \sim \underline{38\ \text{ppm}}$

(5) Consider R2

$x_{R2} = x_b + x_A + x_1$

(a) x_b = 6 ppm

(b) x_A = 4.8 ppm

(c) From Table H4, x_1 = 4.2 ppm

(d) Therefore,

$x_{R2} = 6 + 4.8 + 4.2 = 15.0 \sim \underline{15\ \text{ppm}}$

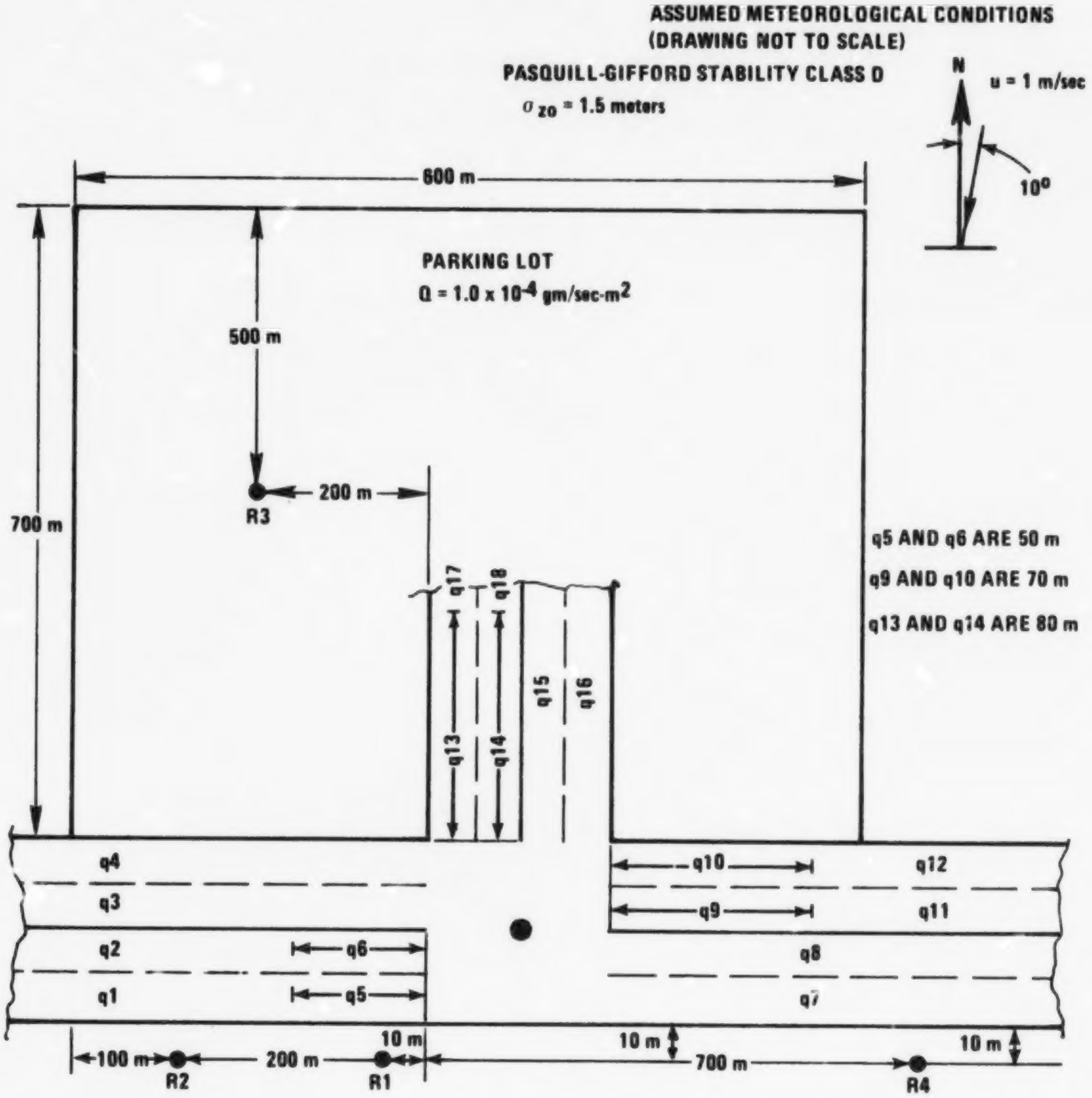

ASSUMED METEOROLOGICAL CONDITIONS
(DRAWING NOT TO SCALE)
PASQUILL-GIFFORD STABILITY CLASS D
σ_{zo} = 1.5 meters
N
u = 1 m/sec
10°
600 m
700 m
500 m
PARKING LOT
Q = 1.0 x 10⁻⁴ gm/sec-m²
200 m
R3
q5 AND q6 ARE 50 m
q9 AND q10 ARE 70 m
q13 AND q14 ARE 80 m
q17
q18
q15
q16
q13
q14
q4
q3
q2
q1
q6
q5
q10
q9
q12
q11
q8
q7
10 m
10 m
10 m
100 m
200 m
700 m
R2
R1
R4

Figure H8. Emissions and receptor sites at the proposed indirect source in example H4.

Table H3. INPUT INFORMATION FOR EXAMPLE H4

Source Designation	West* Coordinates	East* Coordinates	North* Coordinates	South* Coordinates	Emission Intensity (gm/sec-m)
q_1	(0,0,0)	(.360,0,0)	-	-	.0060
q_2	(0,.005,0)	(.360,.005,0)	-	-	.0060
q_3	(0,.010,0)	(.430,.010,0)	-	-	.0040
q_4	(0,.015,0)	(.430,.015,0)	-	-	.0040
q_5	(.360,0,0)	(.410,0,0)	-	-	.0200
q_6	(.360,.005,0)	(.410,.005,0)	-	-	.0200
q_7	(.410,0,0)	(1.0,0,0)	-	-	.0060
q_8	(.410,.005,0)	(1.0,.005,0)	-	-	.0060
q_9	(.430,.010,0)	(.500,.010,0)	-	-	.0180
q_{10}	(.430,.015,0)	(.500,.015,0)	-	-	.0180
q_{11}	(.500,.010,0)	(1.0,.010,0)	-	-	.0040
q_{12}	(.500,.015,0)	(1.0,.015,0)	-	-	.0040
q_{13}	-	-	(.410,.100,0)	(.410,.020,0)	.0160
q_{14}	-	-	(.415,.100,0)	(.415,.020,0)	.0160
q_{15}	-	-	(.420,.220,0)	(.420,.020,0)	.0020
q_{16}	-	-	(.425,.220,0)	(.425,.020,0)	.0020
q_{17}	-	-	(.410,.220,0)	(.410,.100,0)	.0030
q_{18}	-	-	(.415,.220,0)	(.415,.100,0)	.0030

Receptor Site Coordinates* are: R1 (.3975,-.0125,2), R2(.200,-.0135,2), R3(.200,.220,2) and R4(.900,-.0135,2)

*Coordinates are expressed as (km,km,m)

Table H4. LINE SOURCE CONTRIBUTION TO AMBIENT CO CONCENTRATIONS AT THE RECEPTORS IN EXAMPLE H4

Receptor Concentrations			
R1	R2	R3	R4
$x_{q1} = 0$	$x_{q1} = 1.3$	$x_{q1} = 0$	$x_{q1} = 0$
$x_{q2} = 0$	$x_{q2} = 1.3$	$x_{q2} = 0$	$x_{q2} = 0$
$x_{q3} = 0.8$	$x_{q3} = 0.8$	$x_{q3} = 0$	$x_{q3} = 0$
$x_{q4} = 0.8$	$x_{q4} = 0.8$	$x_{q4} = 0$	$x_{q4} = 0$
$x_{q5} = 4.3$	$x_{q5} = 0$	$x_{q5} = 0$	$x_{q5} = 0$
$x_{q6} = 4.2$	$x_{q6} = 0$	$x_{q6} = 0$	$x_{q6} = 0$
$x_{q7} = 0$	$x_{q7} = 0$	$x_{q7} = 0$	$x_{q7} = 1.3$
$x_{q8} = 0$	$x_{q8} = 0$	$x_{q8} = 0$	$x_{q8} = 1.3$
$x_{q9} = 0$	$x_{q9} = 0$	$x_{q9} = 0$	$x_{q9} = 0$
$x_{q10} = 0$	$x_{q10} = 0$	$x_{q10} = 0$	$x_{q10} = 0$
$x_{q11} = 0$	$x_{q11} = 0$	$x_{q11} = 0$	$x_{q11} = 0.8$
$x_{q12} = 0$	$x_{q12} = 0$	$x_{q12} = 0$	$x_{q12} = 0.8$
$x_{q13} = 7.9$	$x_{q13} = 0$	$x_{q13} = 0$	$x_{q13} = 0$
$x_{q14} = 6.6$	$x_{q14} = 0$	$x_{q14} = 0$	$x_{q14} = 0$
$x_{q15} = 1.0$	$x_{q15} = 0$	$x_{q15} = 0$	$x_{q15} = 0$
$x_{q16} = 0.8$	$x_{q16} = 0$	$x_{q16} = 0$	$x_{q16} = 0$
$x_{q17} = 0.4$	$x_{q17} = 0$	$x_{q17} = 0$	$x_{q17} = 0$
$x_{q18} = 0.5$	$x_{q18} = 0$	$x_{q18} = 0$	$x_{q18} = 0$
$x_1 = 27.3$ ppm	$x_1 = 4.2$ ppm	$x_1 = 0$ ppm	$x_1 = 4.2$ ppm

(6) Consider R3

$x_{R3} = x_b + x_A + x_1$

(a) $x_b = \underline{6\ \text{ppm}}$

(b) Note that the distance from site R3 to the upwind edge of the source is:

$$x = \frac{500}{\cos\Theta} = \frac{500}{\cos 10^\circ}$$

Thus x = 508 m

Using Figure H3D and Equation (H3),

$$x_A = (1)\left[\frac{1.0 \times 10^{-4}}{2.35 \times 10^{-5}}\right]_{508} = \underline{4.3\ \text{ppm}}$$

(c) $x_1 = \underline{0\ \text{ppm}}$

(d) Thus, $x_{R3} = 6 + 4.3 = 10.3 \sim \underline{10\ \text{ppm}}$

(7) Consider R4

$x_{R4} = x_b + x_A + x_1$

(a) $x_b = \underline{6\ \text{ppm}}$

(b) $x_A = \underline{0\ \text{ppm}}$

(c) From Table H4, $x_1 = \underline{4.2\ \text{ppm}}$

(d) Thus, $x_{R4} = 6 + 4.2 = 10.2 \sim \underline{10\ \text{ppm}}$

It should be noted that to be strictly correct, the emissions within the parking lot which are treated separately as line sources of pollution, should be subtracted from the emission density used in the area source model. If this were done for receptor R1, it can be seen from Table H3 and Figure H8 that emissions attributable to q_{13} - q_{18} are:

q_{13} = (.0160 gm/sec-m) (80 m) = 1.28 gm/sec

q_{14} = (.0160 gm/sec-m) (80 m) = 1.28 gm/sec

q_{15} = (.0020 gm/sec-m) (200 m) = 0.40 gm/sec

q_{16} = (.0020 gm/sec-m) (200 m) = 0.40 gm/sec

q_{17} = (.0030 gm/sec-m) (120 m) = 0.36 gm/sec

q_{18} = (.0030 gm/sec-m) (120 m) = 0.36 gm/sec

Total = 4.08 gm/sec

$$\text{Emission density to be subtracted} = \frac{4.08 \text{ gm/sec}}{(600 \text{ m})\ (700 \text{ m})}$$
$$= 9.7 \times 10^{-6} \text{ gm/sec-m}^2$$

Thus, the area source emission density should actually be about 0.9×10^{-4} gm/sec-m^2 in the calculations for R1. Generally, total emissions treated as line sources within a parking lot will probably be much less than the total emissions which are treated as an area source.

It is a relatively easy matter to extend analyses such as that performed in Example H4 to estimate typical peak concentrations likely to be encountered by the general public along a sidewalk. The usual procedure would be to estimate typical peak concentrations along the sidewalk on each block. However, sometimes there may be other portions of a sidewalk which are of interest as well. Example H5 illustrates one such case.

Example H5. Suppose there is a sidewalk on the south side of the arterial street pictured in Figure H8 and it is of interest to estimate a typical 1-hour CO concentration along a portion of a sidewalk directly opposite the parking lot (i.e., along a 600-meter length of sidewalk). Assume the centerline of the sidewalk is 5 meters from curbside. The general procedure is to estimate concentrations at receptor points along the sidewalk's centerline and weight these estimates according to what portions of the sidewalk's concentrations they are thought to represent. Generally, it is good procedure to make more calculations around places where queuing occurs, because these concentrations may vary more rapidly than those at mid-block sections. Figure H9 is an enlargement of the bottom portion of Figure H8 showing what might be a good placement of calculation sites.

Following a procedure similar to that outlined in Example H4, 1-hour CO concentrations may be calculated at receptor points 1-7. These turn out to be:

$$\chi_1 = 4.2 + 4.8 + 6 = 15.0 \text{ ppm}$$

$$\chi_2 = 4.2 + 4.8 + 6 = 15.0 \text{ ppm}$$

$$\chi_3 = 17.3 + 4.8 + 6 = 28.1 \text{ ppm}$$

$$\chi_4 = 7.0 + 4.8 + 6 = 17.8 \text{ ppm}$$

$$\chi_5 = 10.0 + 4.8 + 6 = 20.8 \text{ ppm}$$

$$\chi_6 = 4.2 + 4.8 + 6 = 15.0 \text{ ppm}$$

$$\chi_7 = 4.2 + 2.4 + 6 = 12.6 \text{ ppm}$$

Concentrations at these points are then weighted according to the portion of the sidewalk for which they are representative. Thus, the representative concentration along the sidewalk to which the public may be exposed is

$$\chi = \frac{(15.0)(210)+(15.0)(50)+(28.1)(50)+(17.8)(20)}{600 \text{ m}} +$$

$$\frac{(20.8)(70)+(15.0)(130)+(12.6)(70)}{600 \text{ m}}$$

$$\chi = 16.6 \sim \underline{17 \text{ ppm}}$$

The 17 ppm concentration calculated above might be interpreted as the "representative peak" 1-hour concentration encountered by pedestrians moving along the sidewalk where there is no fixed structure or receptor point where exposure to the ambient CO might take place.

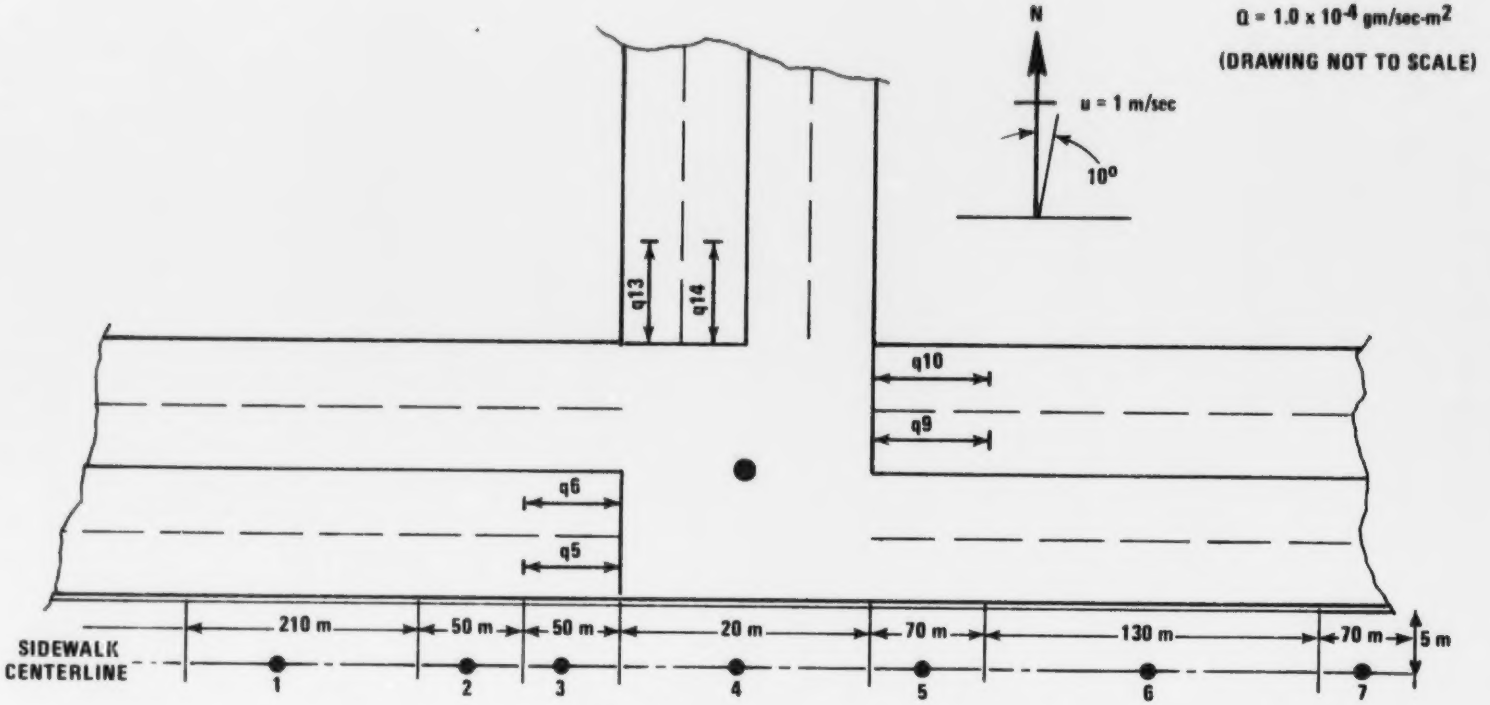

N
u = 1 m/sec
10°
Q = 1.0 x 10-4 gm/sec-m2
(DRAWING NOT TO SCALE)
q13
q14
q10
q9
q6
q5
SIDEWALK
CENTERLINE
210 m
50 m
50 m
20 m
70 m
130 m
70 m
5 m
1
2
3
4
5
6
7

Figure H9. Enlargement of the bottom portion of Figure H8.

HII. Estimation of Representative Concentrations

Representative concentrations are of interest for estimating "typical" concentrations of CO at the site of an indirect source. In addition, estimates of the impact of an indirect source on representative concentrations of HC's, NO_x, oxidants, and CO may provide means for relating the operation of an indirect source to limitations which may be proposed as a part of an air quality maintenance plan or to fulfill no significant deterioration requirements.

A. Representative CO Concentrations

1. Typical Concentrations at the Indirect Source Site

Estimates of typical CO concentrations may be obtained by estimating background concentrations using one of the methods described in Section H.I.A. (or some reasonable alternate method) and superimposing a concentration estimate attributable to activity generated by the source using an area source model similar to the one developed in Section H.I.B. Figures H1A-E, H2A-E, H3A-E, and H4A-E are examples of such area source models. In applying curves similar to those in Figures H1-H4, the emission density estimated using means described in Appendices B-G should be used. It is not necessary to consider emissions from "nearby sources" because it is assumed that "typical" concentrations do not occur in the immediate vicinity of major traffic lanes. Thus, a separate line source analysis is not conducted.

2. Impact of an Indirect Source on Representative CO Concentrations Over Large (> 1 km^2) Areas

The impact of indirect sources on representative CO concentrations over areas greater than or equal to 1 km^2 can be estimated by converting the source's emission density (as estimated in Appendices B-G) to total emission rate and prorating the total emission rate within the appropriate grid square(s). Such a procedure has the obvious disadvantage that the impact of a source can be as little as the investigator wishes, depending on the size of the area over which emissions are prorated. A rule of thumb which may be advisable to follow would be not to prorate emissions over an area extending beyond a distance from the source at which the source exerts less than a 5 percent influence on local traffic volumes. This "5 percent" figure is an arbitrary one which can take both positive and negative values (e.g., presence of a large regional shopping center may actually reduce traffic volume in the vicinity of nearby small shopping centers). The fineness of a superimposed grid is usually limited by emission data and practical considerations to grid squares not less than 1 km^2.

B. Impact of an Indirect Source on Representative HC, NO_x and Oxidant Concentrations

1. Area-wide Quality Analysis

Regulations[3] concerning the review of indirect sources require that certain large proposed airports and highways be reviewed for their potential impact on total nonmethane hydrocarbons, NO_2 and oxidant levels. Use of models to estimate the impact of such a facility on air quality is left open as an option in the regulations. Therefore, a few words concerning the use of such models are in order. Area-wide air quality analysis is frequently thought of as a macro-scale analysis utilizing proportional modeling techniques. Such an analysis embodies estimates of representative concentrations over spatial scales ranging from 1 km^2 to city-wide averages.

2. Proportional Modeling Techniques

Proportional modeling is also widely known as "rollback." The basic relationship is given by Equation (H5).

$$x = (ef)(gf)(c-b) + b \tag{H5}$$

where

x = estimated concentration of the pollutant of interest

ef = emission factor ratio reflecting application of new technology to sources emitting the pollutant of concern

gf = growth factor ratio for sources emitting the pollutant of concern

c = base period concentrations of the pollutant of interest b = background concentrations of the pollutant of interest

If it is decided to use such an approach, it is recommended that the "modified rollback" technique be employed.[23] Modified rollback provides some flexibility in that it allows the user to distinguish source categories on the basis of differing growth rates, applicable emission control technologies and typical heights of emission. A distinction can also be made on the basis of interest. For example, if it were of interest to determine the effect of a new highway (with resulting increases in truck traffic) on air quality, the capability exists to examine the impact of heavy-duty vehicles explicitly.

There are several problems with the rollback approach which require extreme caution to be used in its application to indirect source review.

a. The impact of the source is completely dependent on the size of the area chosen for analysis. This problem was discussed in connection with the use of meso-models to estimate representative CO concentrations. The problem is aggravated with rollback models, however, because future concentrations are estimated by comparison of new with existing emissions. Consider the case of an airport built on a 10 mi x 10 mi plot of vacant land. If this 10 mi x 10 mi plot were chosen for analysis, the impact on air quality estimated by a rollback approach would be indeterminate since the base period emissions were zero (implying a growth factor ratio of infinity) and the base period concentrations are equivalent to background levels.

b. Proportional changes in emissions are assumed to be made throughout the area of interest, or pollutants are assumed to be perfectly mixed throughout the area of interest so that changes in existing concentrations are proportional to changes in the total emissions throughout the area of interest. These assumptions are highly dubious in the application of rollback models to indirect source review. Consider the situation posed by the highway located on the edge of a town with two air quality monitoring stations. One station is located on the edge of town near the proposed highway site while the other is located downtown. Suppose the base concentration at the downtown site were 4 times that at the site near the proposed highway. An indiscriminate application of the rollback approach (using the above assumptions) would indicate an absolute change in base level concentrations 4 times higher at the downtown site than at the nearby site.

3. Use of Proportional Modeling in Estimating the Impact of an Indirect Source on Representative Oxidant Concentrations

Since oxidants are secondary pollutants (i.e., they occur in the atmosphere as the result of chemical reactions rather than as emissions from sources), proportional modeling techniques must be altered in order to address oxidants. Such alterations are needed because the emission factor and growth factor ratios in Equation (H5) cannot be applied to oxidants per se. Two approaches are available:

a. For base level oxidant concentrations exceeding 0.20 ppm. Emission and growth factor ratios in Equation (H5) should pertain to total non-methane hydrocarbon emissions while base level and background concentrations should pertain to oxidant concentrations. The estimated oxidant concentrations, reflecting the impact of the indirect source's hydrocarbon emissions, should be obtained using Equation (H5).

b. For base level oxidant concentrations less than or equal to 0.20 ppm. Appendix J in the August 14, 1971 Federal Register[24] should be used to assess the impact of the change in total non-methane hydrocarbon emissions attributable to the indirect source on base level oxidant concentrations.

4. Use of Photochemical Meso-Models

As a result of the problems in applying proportional models to estimate the impact of an indirect source on representative concentrations of pollutants, it is strongly recommended that, whenever feasible, validated meso-models for photochemical pollutants, such as the SAI model,[25] replace the proportional modeling approach. Such models incorporate reaction mechanisms among hydrocarbons, NO_x and oxidant concentrations. If the proposed reaction rates and mechanisms are appropriate for the geographical area under study, such models provide a much more flexible basis for assessing the impact of an indirect source on spatial distributions of representative concentrations of photochemical pollutants.

HIII. Estimation of 8-hour Concentrations

A. Relationship to Meteorological Variables

There are three meteorological variables which are of greatest importance in the application of area and line source micro-models for the review of indirect sources. These variables are atmospheric stability, wind speed and wind persistence.

Atmospheric stability is indicative of the rate at which pollutants mix within the atmosphere. Generally, for sources and receptors at similar heights, the impact of a source becomes more severe with increasing stability. In estimating the most stable atmospheric stability likely to occur in the vicinity of an indirect source during hours of operation, note should be taken of the possible effects of mechanical turbulence. Such turbulence may be likely to ensue as the result of aerodynamic effects of buildings, motion of vehicles and heat island effects. As a result of this increased turbulence, pollutants are likely to mix and become diluted more readily than would otherwise be the case in a rural area. Such conditions may preclude the most stable atmospheric conditions (Pasquill-Gifford Classes E and F) from occurring. One study[20] noted better agreement between observed and estimated CO concentrations at a shopping center if a stability estimation technique based on sky cover and wind speed which appears in the Workbook of Atmospheric Dispersion Estimates[16] were assumed. Alternatively, a stability classification system based on observations in urban areas (e.g., McElroy-Pooler classifications) might be used. Figures H1 - H4 illustrate the sensitivity of an area source model's predictions to varying assumptions about atmospheric stability. To be consistent, the same stability assumptions made in applying the area source model should be applied with a line source model.

Wind speed is indicative of the quantity of air into which pollutants are emitted per unit of time. Since rise of a plume centerline above the physical height of emissions is not ordinarily an important consideration in evaluating the impact of an indirect source, concentrations can usually be assumed to be inversely proportional to wind speed. For example, in Figure HID a wind speed of 1 m/sec is assumed. To estimate CO concentrations with a 2 m/sec wind speed with all other conditions identical, the concentrations obtained using Figure HID would simply be multiplied by "1/2."

Wind persistence in the context used herein refers to the amount of time for which a narrow range of wind speeds (e.g., ± 0.5 m/sec) and directions (e.g., ± 10°) prevail. Since most dispersion models assume steady state meteorological conditions, persistence may be the key determinant of how well estimates and observations agree. The problem of wind speed persistence is not a particularly crucial one, since it is a relatively easy matter to use the time-averaged wind speed to estimate the time-averaged concentration provided emissions and wind direction remain constant. Wind direction persistence forms the crux of the problem, because a change in direction may radically alter the source-receptor configuration. Two observations with regard to wind direction persistence:

1. Wind direction becomes increasingly likely to change with time;

2. Wind direction persistence decreases with lowering wind speeds.

These observations indicate that the use of steady state models are less likely to be appropriate for estimating 8-hour concentrations during periods of low wind speeds than usual.

B. Methods for Estimating 8-hour Concentrations for CO

There is no completely satisfactory method for estimating 8-hour CO concentrations. Several alternative methods, with their pros and cons, are described below. All of the methods described are empirical in nature in that they require one to examine either variations in meteorological conditions or variations in observed CO concentrations at facilities which are similar to the one which is proposed.

Method (1): Evaluate air quality monitoring data obtained at an existing indirect source which is similar to the proposed source. Note the ratio between maximum observed 8-hour concentration and maximum observed 1-hour concentration obtained during 1-hour periods in which low wind speeds (e.g., < 2 m/sec) prevail. Note the corresponding 1-hour and 8-hour average traffic (veh/hr) utilizing the source. Factor out the difference in observed traffic for the 1- and 8-hour periods. The resulting ratio may then be used to multiply estimated 1-hour concentrations to obtain 8-hour concentration estimates. This method is illustrated in Example H6.

Example H6: At an existing indirect source, suppose 1-hour traffic volume demand during the hour of the maximum observed CO concentration is 1000 veh/hr and the average hourly traffic volume demand during the 8-hour period of interest is 800 veh/hr. Maximum observed 1-hour concentration is 24 ppm and maximum observed 8-hour concentration is 6 ppm. By what factor should 1-hour concentration estimates at a proposed source be multiplied to obtain estimates for 8-hour CO concentrations?

$$\text{Required Factor} = \left(\frac{6}{24}\right)\left(\frac{1000}{800}\right) = 0.31$$

Pros: (a) Deals directly with air quality data observed at existing similar facilities.

(b) Easy to use.

Cons: (a) Depends on availability of appropriate data from existing sources.

(b) Ratio may vary depending on the location of the receptor.

(c) Assumes that the meteorology at the existing source is similar to that at the site of the proposed source.

Method (2): Brute Force Method. Simulate hourly average concentrations at specified receptor sites at a proposed indirect source using suggested estimation techniques for 1-hour concentrations and observed traffic and meteorological data. Keep track of running 8-hour average concentrations. Choose highest concentration at each receptor.

Pros: (a) Based on past observations.

(b) Is location-specific.

Cons: (a) Requires much manpower and computer time.

(b) There is no assurance that because a particular sequence of meteorological and traffic events happened once, it will happen again. Also, there is no assurance that the worst sequence of events has been observed.

Method (3): Construct conditional hourly wind direction change ($\Delta\theta$) frequency distributions[26] for low wind speeds using observed data for the peak 8-hour period of use. Use these $\Delta\theta$ frequency distributions in a simulation of the proposed indirect source in which receptor points have been strategically placed. Repeat this simulation for a number (e.g., 100) of 8-hour periods. Select the highest ratio between estimated 1-hour and 8-hour concentrations at each receptor as the basis for estimating the 8-hour concentrations.

Pros: (a) Based on meteorological observations.

(b) Is location-specific within the indirect source.

Cons: (a) Involves careful analysis of meteorological data.

(b) Requires computer analysis.

Method (4): Examine available meteorological observations to note maximum observed lengths of time in which wind direction is constant (e.g., ± 10°) for various ranges of wind speeds. If the longest observed period of direction persistence is less than 8 hours for a given range of wind speed, divide this period (in hours) by "8" and multiply the quotient by the concentration estimate obtained for a one-hour period. For example, if the longest period of wind direction persistence for winds ≤ 2 m/sec were observed to be 6 hours and the one hour concentration were 4 ppm,

$$\chi = (4)\ (6/8) = 3 \text{ ppm}$$

Pros: (a) Relatively simple to apply once data have been examined.

(b) Similar, in principle, to a method sometimes used to estimate 24-hour concentrations arising from point sources.

Cons: (a) Since an indirect source is evaluated by area and line source models, the source's impact at a given receptor may not cease with a change in wind direction.

(b) Definitions of wind speed ranges and what constitutes change in wind direction are arbitrary.

(c) Does not consider variations in atmospheric stability.

Method (5): Use air quality data collected at existing indirect sources to estimate standard geometric deviations (SGD) for 1-hour concentrations. Use the derived SGD's and the mean observed 1-hour concentration to estimate the 8-hour concentration which is exceeded 0.1% of the time using Larsen's statistical transforms.[12-14] It should be noted that the standard geometric deviation at an indirect source should be somewhat greater than those observed at typical monitoring stations because concentrations will be more sensitive to the direction of the wind.

Pros: (a) Uses air quality data observed at existing indirect sources.

(b) Enables estimate of peak, 2nd highest, median, lowest or any percentile 8-hour concentration.

Cons: (a) Depends on there being air quality data available from existing sources.

(b) Standard geometric deviation may be very sensitive to the relative position of source and receptor.

(c) Assumes the meteorological characteristics at the existing and the proposed source are similar.

REFERENCES

(1) U. S. EPA, Office of Air Quality Planning and Standards (Monitoring and Data Analysis Division), and National Environmental Research Center (Quality Assurance and Environmental Monitoring Laboratory); "Guidance for Air Quality Monitoring Network Design and Instrument Siting"; OAQPS No. 1.2-012; Research Triangle Park, N. C. 27711; (January 1974).

(2) Personal Communication, Mr. William F. Hunt, Jr., U.S. EPA, Office of Air Quality Planning and Standards, Monitoring and Data Analysis Division, Research Triangle Park, N. C. 27711.

(3) 40 CFR 52; "Approval and Promulgation of Implementation Plans: Review of Indirect Sources"; Federal Register; (July 9, 1974); p. 25292.

(4) Ludwig, F. L. and R. L. Mancuso; "Users Manual for the APRAC-1A Urban Diffusion Model Computer Program" Prepared for U.S. EPA, Meteorology Laboratory, Research Triangle Park, N. C. 27711 (Sept. 1972).

(5) Busse, A. D. and J. R. Zimmerman; "Users Guide for the Climatological Dispersion Model"; EPA-R4-73-024; U.S. EPA, NERC, Research Triangle Park, N. C. 27711; (June 1973).

(6) U.S. EPA; "Air Quality Display Model"; PB 189 194; National Technical Information Service, Springfield, Va. 22161; (November 1969).

(7) Hanna, S. R.; "Simple Methods of Calculating Dispersion from Urban Area Sources"; COM-72-10999; National Technical Information Service; Springfield, Va. 22161; (1971).

(8) Hanna, S. R.; "A Simple Method of Calculating Dispersion from Urban Area Sources"; JAPCA 21; (1971) p. 714.

(9) Gifford, F. A. and S. R. Hanna; "Modeling.Urban Air Pollution"; Atm. Env. 7; (1973); p. 131.

(10) Turner, D. B. and A. D. Busse; "Users' Guide to the Interactive Versions of Three Point Source Dispersion Programs: PTMAX, PTDIS and PTMTP"; U.S. EPA, NERC, Research Triangle Park, N. C. 27711; (June 1973).

(11) Zimmerman, J. R. and R. S. Thompson; "Users' Guide for HIWAY: A Highway Air Pollution Model; Environmental Monitoring Series EPA-650/4-008; U.S. EPA, NERC, Research Triangle Park, N. C. 27711 (February 1975).

(12) Larsen, R. I.; "A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards". OAP Publication No. AP-89; U.S. EPA, Research Triangle Park, N. C. 27711; (November 1971).

(13) Larsen, R. I.; "An Air Quality Data Analysis System for Interrelating Effects, Standards and Needed Source Reductions"; JAPCA 23; (November 1973).

(14) Larsen, R. I.; "An Air Quality Data Analysis System for Interrelating Effects, Standards and Needed Source Reductions -- Part 2"; JAPCA 24; (June 1974).

(15) Holzworth, G. C.; "Mixing Heights, Wind Speeds and Potential for Urban Air Pollution Throughout the Contiguous United States"; OAP Publication No. AP-101; U.S. EPA, Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711.

(16) Turner, D. B.; "Workbook of Atmospheric Dispersion Estimates"; PHS Publication No. 999-AP-26; U.S. EPA; Research Triangle Park, N.C. 27711; (1969).

(17) McElroy, J. L. and F. Pooler, Jr.; "St. Louis Dispersion Study Volume II--Analysis"; NAPCA Publication No. AP-53; U.S. EPA, Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711. 27711; (December 1968).

(18) Dabberdt, W. F. and R. Sandys; "Assessment of the Air Quality Impact of Indirect Sources" SRI Report prepared for J. C. Penney Co., Inc.; Stanford Research Institute, Menlo Park, Ca.; (November 1973).

(19) Bach, W. D., B. W. Crissman, C. E. Decker, J. W. Minear, P. P. Rasberry and J. B. Tommerdahl; "Carbon Monoxide Measurements in the Vicinity of Sports Stadiums"; EPA-450/3-74-049; U. S. EPA, Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711. (July 1973).

(20) Patterson, R. M., R. M. Bradway, G. A. Gordon, R. G. Orner, R. W. Cass and F. A. Record; "Validation Study on Approach for Evaluating the Impact of a Shopping Center on Ambient Carbon Monoxide Concentrations"; EPA-450/3-74-059; U.S. EPA, Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711. (August 1974).

(21) Ott, W. and R. Eliassen; "A Survey Technique for Determining the Representativeness of Urban Air Monitoring Stations with Respect to Carbon Monoxide"; JAPCA 23 No. 8; (August 1973).

(22) Patterson, R. M. and F. A. Record; "Monitoring and Analysis of Carbon Monoxide and Traffic Characteristics at Oakbrook"; EPA-450/3-74-058; U. S. EPA, Air Pollution Technical Information Center, Research Triangle Park, N. C. 27711. (November 1974).

(23) de Nevers, N. and J. R. Morris; "Rollback Modeling--Basic and Modified"; Paper 73-139 presented at 1973 Annual Air Pollution Control Association Meeting; Chicago, Illinois; (June 1973).

(24) 42 CFR 420; "Requirements for Preparation, Adoption and Submittal of Implementation Plans--Appendix J"; Federal Register 36; No. 158; (August 14, 1971); p. 15[illegible].

(25) Systems Applications, Inc.; "Urban Air Shed Photochemical Simulation Model Study--Volumes I-III"; EPA-R4-73-030g; U.S. EPA, Office of Research and Development, Washington, D. C.; (July 1973).

(26) Meyer, E. L., Jr. and J. E. Quon; "A Method for Simulating Wind Conditions During Atmospheric Stagnation Periods"; J. Appl. Met. 11; (August 1972).

APPENDIX I. COMPILATION OF INDIRECT SOURCE MONITORING STUDIES

This appendix is intended to provide guidance concerning a more detailed analysis of proposed indirect sources should this be necessary or desirable pursuant to 40 CFR 52.22(b). The materials contained herein are offered as suggestions. Alternate analytical approaches for evaluating the impact of a proposed source may be used if it can be demonstrated that they are more applicable to the source under review.

U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, N. C. 27711

January 1975

APPENDIX I.

COMPILATION OF INDIRECT SOURCE MONITORING STUDIES

The following set of abstracts is the result of a search for studies which were related to indirect sources and which included air quality monitoring at the study site. The studies identified have been compiled from awareness of studies completed or underway, from a computerized literature search provided by APTIC, or from an extensive telephone canvassing effort. The inclusion of a study in Appendix I in no way implies EPA endorsement of the results or conclusions drawn. The purpose of this Appendix is to acquaint the agency or individual charged with the task of evaluating the impact of an indirect source on air quality with the scope of previous studies and with potential sources of additional information.

In order to keep the effort within reasonable limits, and more importantly to limit the information supplied to the Guidelines Document user to that which would be truly helpful, a large number of the studies or abstracts reviewed were rejected. The only absolute criterion was that the study had to include air quality measurements related to automotive emissions associated with an indirect source. Various other reasons for omitting studies were:

1. No traffic or meteorological data.

2. Meager quantities of air quality data especially in older studies.

3. Lack of definitive information in an abstract coupled with an untranslated foreign text (there were perhaps 100 abstracts of Japanese text studies produced by the APTIC search. There may be valuable information included in these studies but the information in the abstract would not justify the effort required for the average guidelines document user to have a translation made).

The format used to report the studies includes the following headings:

1. Study Title
2. Sponsoring Agency
3. Agency/Contractor (if applicable)
4. Agency/Contractor (performing monitoring)
5. Report
6. Abstract

A brief explanation of the information included with each heading will be helpful to understand the flexibility which was used in preparing each report.

Study Title: On formal studies or studies for which a report has been written the use of this heading is obvious. For some studies which are in preparation or for some reason a title was not given, a descriptive phrase is used as a title. In the cases where a descriptive phrase is used a series of periods (. . .) is used before and after the phrase.

Sponsoring Agency: The entry here is usually the direct sponsor for the study. In some studies with complex sponsorship the relationships were not clear from the material obtained, and the sponsor listing may not be complete.

Agency/Contractor (if applicable): The name of the agency or firm responsible for the overall study is included in those cases where a prime contractor subcontracted some or all of the monitoring work. Frequently this information was not appropriate or was not known. In these cases no entry was made.

Agency/Contractor (performing monitoring): The name of the firm which actually set up and maintained the monitoring instruments is entered. In those studies where there was only an abstract to work from, e.g., from the APTIC literature search, it could not be determined who performed the monitoring.

Report: The entry here is one of the following:

a. The formal designation of the report; e.g., company and report number.

b. The type of report; e.g., final report to EPA for contract.

c. A publication reference to the report; e.g., publication title, volume and number.

d. NTIS identification number.

e. APTIC abstract number.

For those studies for which information was provided from a telephone conversation, there is no entry after this heading.

Abstract: Whenever possible the author abstract is included with any additional information which was thought necessary. When a suitable abstract was not available, an abstract was either prepared from the report, from summaries or other descriptive material supplies, or from information obtained by telephone interview, as appropriate. Whenever it was definitely known that actual traffic counts or on-site meteorological data was collected, that information is so stated.

Study Title:	AIR POLLUTION AT HEATHROW AIRPORT, LONDON APRIL-SEPTEMBER 1970
Sponsoring Agency:	
Agency/Contractor (If Applicable):	
Agency/Contractor (Performing Monitoring):	Warren Spring Laboratory, Department of Trade and Industry, England
Report:	Paper 710324 Presented at SAE/DOT Conference on Aircraft and the Environment, Washington, D.C., February 8-10, 1971

ABSTRACT

Calculations have been made of total pollution emissions at Heathrow Airport, London, from aircraft operations, heating installations and road traffic. Comparisons were made of concentrations of pollution levels from the airport and from nearby residential areas. Measurements of smoke, sulphur dioxide, oxides of nitrogen, carbon monoxide, total hydrocarbons and deposited matter were also carried out in different parts of the airport.

The results showed that the airport was not contributing unduly to local pollution. At no time did pollution concentrations at the airport ever exceed values which have been found in Central London. The highest values obtained came from road traffic in the Central Area.

Study Title:	MODEL VERIFICATION - AIRCRAFT EMISSIONS IMPACT ON AIR QUALITY
Sponsoring Agency:	Environmental Protection Agency
Agency/Contractor (If Applicable):	GEOMET, Incorporated
Agency/Contractor (Performing Monitoring):	GEOMET, Incorporated
Report:	Final Report to E.P.A. for Contract No. 68-02-0665

ABSTRACT

Under EPA contract, GEOMET completed a program of air quality measurement, model development and model validation at Washington National Airport.

The measurement program generated six months of records of air quality data, airport operational data, and meteorological data, some of which were used in the model development and validation, and all of which are recorded in edited, processed form on magnetic tape for future use.

Seven air quality monitoring sites were located on the airport with continuous measurement of carbon monoxide and particulates. At three of the seven sites total hydrocarbons, methane, nitrogen dioxide, ozone and coefficient of haze was also measured continuously. At one station meteorological data was recorded continuously. Meteorological and air quality data were collected during October 1972 through April 1973.

The model development work started from a model developed previously by Northern Pesearch and Engineering Corporation (NREC), which had been previously shown by others to generally underpredict concentrations by a factor of about ten. In this project, the first step was to make a number of improvements in implementing the model, without basically changing the model itself. Briefly, these may be summarized as: the use of different methods (from those used by NREC and others): for calculating single values of short-term concentrations; for calculating maximum values of short-term concentrations; and for calculating long-term average values of concentrations. For the first of these three, the change involved the dropping of a superimposed wind direction variabliity parameter, substituting a single direction only. The next two were handled jointly by calculating long-term average concentrations from a sufficiently large sample of single short term values, rather than the NREC use of the joint frequency distribution of meteorological conditions. This also provides better estimates of maxima than, as NREC does, calculating presumed maxima based on the selection of the meteorological condition judged to cause the highest concentrations. The NREC model with this improved implementation was applied to make estimates of the non-reactive pollutants (carbon

monoxide and particulates). This model still consistently underpredicted; however, now the combined estimated station median and mean values were low by factors ranging from 1.5 to 4, rather than the rpeviously stated factor of 10.

Further more significant modifications were then made to the model, in the form of an improved aircraft classification system, improved aircraft operational modes and pollution emission rates, increased and improved details of airport representation, improved environ area source modeling and emission rates, more representative depiction of line sources, and inclusion of major peripheral highways. This is called the modified (GEOMET) model.

The final result of much validation analysis showed the modified (GEOMET) model as consistently predicting near the mean and median values for CO and particulates (ranging from 16 percent underprediction to 36 percent overprediction); an occasional tendency to overpredict by as much as a factor of two for some of the higher percentile values is explained and can be accounted for in model use.

1 - AIRPORT

Study Title:	ANALYSIS OF AIRPORT AIR QUALITY MONITORING DATA
Sponsoring Agency:	Federal Aviation Administration
Agency/Contractor (If Applicable):	Northern Research and Engineering Corporation
Agency/Contractor (Performing Monitoring):	Environmental Research and Technology, Inc.
Report:	Paper 73-156 given at 66th Annual Meeting of the Air Pollution Control Association, Chicago, Illinois, June 24-28, 1973

ABSTRACT

The body of information presented in this paper is directed to persons who are concerned with the general level of air quality at airports and who are also concerned with understanding the relationship between airport ground operations and the resultant time and spatial variations in air pollution concentrations within the airport boundaries. The paper describes the results of an air quality measurements program conducted at a major urban airport (Washington National Airport). Five pollutants (CO, NO_x, HC, TSP, and SO_2) were monitored continuously at three sites for a 3-month winter period (December 1971 through March 1972), and for a 1-month summer period (August 1972). In addition, CO was monitored at a fourth site throughout each sample period.

A detailed analysis of the CO data describes compliance with ambient air quality standards, diurnal variations in average hourly observations, and correlations between meteorological conditions and observed worst case CO levels. In addition, pollution roses for the CO data are analyzed to determine correlations among air quality, meteorological conditions, and emission source strength.

Results of the study indicate that CO violates ambient standards, and that the highest observed concentrations occur in the immediate vicinity of the terminal gate areas. The analysis of the pollution roses indicates that: (1) significant variations in CO concentration levels occur within short distances within the airport boundaries; (2) building structures and heavily traveled roadways represent significant influences on the observed spatial air quality patterns; and (3) high CO concentrations over the sampling period are due primarily to high source emissions rather than to adverse meteorological conditions.

Study Title:	SEA-TAC/COMMUNITIES PLAN
Sponsoring Agency:	Port of Seattle and King County, Washington
Agency/Contractor (If Applicable):	Environmental Systems Laboratories, Inc.
Agency/Contractor (Performing Monitoring):	Environmental Systems Laboratories, Inc.
Report:	Six-Month Summary Report of Progress

ABSTRACT

Background - Increased levels of air traffic intensity coupled with increased residential development in nearby communities has created land use problems in some areas of those communities. A Sea-Tac International Airport and Vicinity Master Plan Project has been initiated to resolve the incompatibility of the airport use and community development.

The Port of Seattle and King County are jointly sponsoring the study. Two-thirds of the study cost is financed through an Airport Master Planning Grant from the Federal Aviation Administration (FAA). The study project was initiated in March 1973, and reports of progress are issued at six-month intervals.

Environmental studies is one of the five major efforts of the study project. The environmental studies include: (1) noise exposure, (2) air quality, (3) water quality/drainage, (4) solid waste, (5) natural determinants, (6) aesthetic and visual characteristics, and (7) community attitudes.

Air quality measurements were made at two sites in close proximity of the airport. At each site vans with equipment to measure concentrations of (1) carbon monoxide, (2) hydrocarbons, (3) nitrogen oxides, (4) particulates, (5) oxidants were set up and operated during June and September 1973 by Environmental Systems Laboratories, Inc. of Sunnyvale, California. Predictions of future air quality levels were computed using a computer model. The data collection was to include nine weeks of air quality monitoring. Comparison of the existing and forecast levels of those pollutants to the Federal primary air quality standards indicated the standards would not be exceeded in the 1973-1993 time period.

A study of surface transportation is included as part of the overall study but traffic data were not available in the documents reviewed. Air quality data for the Sea-Tac Communities Plan were reported by Environmental Systems Laboratory in two reports: 1. Sea-Tac Air Quality-Preliminary, Sunnyvale, California, October 12, 1973 and 2. Addendum, Sea-Tac Air Quality-Preliminary, Sunnyvale, California, October 12.

Study Title:	BOSTON-LOGAN INTERNATIONAL AIRPORT PRELIMINARY ENVIRONMENTAL IMPACT REPORT FOR A PROJECT TO EXTEND RUNWAYS 4L AND 9 AND CONSTRUCT STOL/GA RUNWAY 15-33
Sponsoring Agency:	Massachusetts Port Authority
Agency/Contractor (If Applicable):	Landrum & Brown, Inc.
Agency/Contractor (Performing Monitoring):	Booz, Allen & Hamilton, Inc., Environmental Resources Group
Report:	Appendix E. Environmental Impact Statement for Extension of Runways 4L and 9 and Construction of STOL/GA Runway 15-33 at Logan International Airport

ABSTRACT

Air quality data for Logan International Airport were compiled by Booz, Allen & Hamilton, Environmental Resources Group and reported in a Draft Environmental Impact Statement required for proposed construction work which would extend runways 4L and 9 and construct STOL/GA runway 15-33. The report is dated July 1973 and was available for review from E.P.A. Region I office in Boston. Appendix E of that report provides the air quality data pertinent to the proposed airport changes.

Air quality measurements were made for three one-week periods in the winter of 1972. Measurements of sulfur dioxide, nitrogen dioxide, coefficient of haze, carbon monoxide and hydrocarbons were made at various locations both on and off the airport. Not all pollutants were measured at each site. The air quality data collected were combined with air quality data collected in the spring of 1971 and were thus considered to be an adequate sample to represent the airport and environs.

Continuous (24 hour) particulate sampling was carried out at six selected sites on the airport property. Samples for the gaseous pollutants were collected at the downwind end of the most active runway two to four times a day during the sampling periods.

Analysis of the data collected indicates the ambient air at the airport is generally of better quality than the air in the urban area of Boston. Calculations were made which show the aircraft operations cause less than one-half of one percent of the formation of the five principle air pollutants generated in the Metropolitan Boston area. Projections of aircraft emissions for 1980 were made in order to compare the possible alternatives to the airport plan and the impact on air quality which would result from those alternatives.

1 - AIRPORT

Study Title: AIRPORTS AS TRACE METAL SOURCES: A STUDY OF FRIENDSHIP INTERNATIONAL AND WASHINGTON NATIONAL AIRPORTS

Sponsoring Agency: U.S. Atomic Energy Commission Contract Number AT-(40-1)-4028 and National Science Foundation RANN Program Grant No. GI 36338X

Agency/Contractor (If Applicable): University of Maryland

Agency/Contractor (Performing Monitoring): University of Maryland

Report: Master's Thesis - Tomas J. Conry

ABSTRACT

Samples of atmospheric particulate material were collected using filters at Baltimore's Friendship International, and Washington's National Airports. These samples were analyzed by instrumental neutron activation analysis for about 20 trace elements to determine if trace metals are emitted in significant quantities by airports. A few samples were collected using a cascade impactor to determine the size distribution of the observed atmospheric trace elements. Samples were collected during the winter of 1972-73.

The emissions were usually characteristic of vehicular activity and other sources around the airports rather than aircraft. Some elements that showed downwind enrichments did correlate with aircraft and service vehicle activity: Na, Ba, V, Mn, Zn, As, Se, Sb. Correlation with wind direction indicates that small amounts of V, Mn, Zn, As, and Se are coming from aircraft activity.

Study Title:	STUDY OF JET AIRCRAFT EMISSIONS AND AIR QUALITY IN THE VICINITY OF THE LOS ANGELES INTERNATIONAL AIRPORT
Sponsoring Agency:	Environmental Protection Agency
Agency/Contractor (If Applicable):	Los Angeles County Air Pollution Control District
Agency/Contractor (Performing Monitoring):	Los Angeles County Air Pollution Control District
Report:	NTIS No. PB 198 699

ABSTRACT

A study was conducted at Los Angeles International Airport (LAX) in 1968 to obtain the most complete and comprehensive information possible on the kinds and quantities of air contaminants emitted by jet aircraft. A later study was made at LAX during the period June 30, 1969 through November 18, 1970. Specific objectives of this study were to determine:

- Total pollutant emissions from aircraft and ground operations.
- Measurement of exhaust emissions from Pratt & Whitney JT4A and JT9D engines to complete the emission data previously obtained by APCD for other contemporary gas turbine aircraft engines.
- Atmospheric concentrations of CO and particulate matter at ground level within and around the airport.
- Measurement of CO exposure within aircraft cabins during all ground operations.

Measurements of ambient concentrations of CO and suspended particulates were made at fixed and mobile sites outside airport locations, inside airport terminals, and in residential and commercial areas on a 2-mile radius of the airport.

Background concentrations were continuously measured at two sites. Mobile monitoring stations were set up at 41 different locations where they were operated each weekday and on six weekend days for a continuous 6-hour period.

Estimates were developed for a large variety of ground operations routinely carried on in support of aircraft operations. Special tests were made to measure CO concentrations inside an aircraft cabin during the period when passengers are loaded through the time when the aircraft

idled on the runway prior to take-off. Conclusions as to the extent of impact aircraft operations have on air quality are given as well as data for the derived emission estimates and a summary of data from the air quality monitoring stations. Some major conclusions from this study are summarized below:

Aircraft and Ground Operations

Jet flights account for 53 percent of the total atmospheric pollution burden generated within the boundary of Los Angeles International Airport (LAX). About 90 percent of the particulate matter and 72 percent of the hydrocarbons in this total originate from jet sources.

Ground operations account for 42 percent of total air contaminant emissions and 55 percent of total CO emissions at LAX.

LAX is a significant area source of air contaminants, generally upwind of metropolitan Los Angeles.

The 6.7 tons of particulate matter emitted daily in the 4.7 sq mi LAX source area exceeds the atmospheric loading rate of particulates from any area of comparable size in Los Angeles County.

About 70 percent of total jet aircraft operation time to and from 3500 ft altitude, is spent in the idle and taxi mode, which accounts for about 55 percent of total aircraft emissions.

Particulate emissions from jet aircraft engines are very conspicuous during both final approach and take-off. However, about 40 percent of particulate matter emitted from jet flights occurs during taxi and idle modes after arrival touchdown and before initiating the take-off run.

The JT8D engine emits total air contaminants at a rate about twice that of any of the other six models tested.

Atmospheric Measurements

One result of airport activities is an increased soiling effect. Atmospheric contamination measurements of particulates by Km show significantly higher values in the airport area than at a location several miles removed, such as Downtown Los Angeles, although total weight of particulate material, Hi-Vol, varies little between the areas.

Monthly average CO values at Downtown Los Angeles (4-6 ppm) and Lennox (6-7 ppm) are within the range of ambient concentrations measured at the airport stations (2-18 ppm).

CO levels at paired inside-outside sampling locations, with one exception, are higher at the inside station. Statistical analysis indicates that higher internal readings are caused by undetermined emission sources.

The emission inventory indicated that auto traffic is an appreciable contributor to the observed contaminant levels and should be considered in any appraisal of the impact of an airp[illegible] the surrounding community.

Aircraft Cabin Air Sampling

During runway operations, carbon monoxide concentrations in aircraft cabins ranged from 2 to 7 ppm and usually averaged 4 ppm. These values are compared to airport background values and significantly lower than levels to which the air traveler is exposed during his stay at the air terminal prior to taxiing onto the runway.

1 - AIRPORT

Study Title:	VEHICLE BEHAVIOR IN AND AROUND COMPLEX SOURCES AND RELATED COMPLEX SOURCE CHARACTERISTICS SUBTASK 2 - AIRPORTS
Sponsoring Agency:	Environmental Protection Agency
Agency/Contractor: (If Applicable)	
Agency/Contractor: (Performing Monitoring)	GEOMET, Incorporated
Report:	Task Report under EPA Contract Number 68-02-1094 Task Order Number 3

ABSTRACT

The project consisted of a task, under a task order level of effort type of contract, to "collect, analyze and integrate technical data, and develop methodologies which can be used to provide guidelines for EPA and state agencies in reviewing and evaluating proposed new or expanded complex sources." The principal technical effort involved quantitatively relating the physical characteristics of each type of complex source to automobile movements, numbers, and engine running times or speeds.

For the six complex source types which involve parking facilities (shopping centers, airports, sports stadiums, parking facilities, recreational areas, and amusement parks), the methodology involved developing the concept of combining the numbers of cars operating, with a characteristic time of operation. Both of these parameters have characteristic and peak values depending on the type of source and its physical and operational characteristics; methods of calculation of appropriate values are given, to permit use in emission and air quality estimations.

For the seventh complex source (major highways), for which parking is not a factor, a different principle was developed for relating parameters descriptive of highway traffic to highway parameters. Briefly, one approximation technique which was developed, relates operating speed to design speed and the ratio of volume demand to capacity, and then evolves this into equivalent vehicle miles travelled. A more precise technique develops traffic density for specified highway segments, from volume demand and operating speed; emission rates can then be derived from consideration of unit emission rates, operating speed, and traffic density.

The seven methodologies have been used by EPA as the basis for guidelines which relate complex source characteristics to traffic behavior parameters (described above), thence to emissions, and finally to air quality estimates.

1 - AIRPORT

Study Title: AIRPORT VICINITY AIR POLLUTION STUDY AT O'HARE INTERNATIONAL AIRPORT, CHICAGO, ILLINOIS AND ORANGE COUNTY (CALIFORNIA) AIRPORT

Sponsoring Agency: Federal Aviation Administration

Agency/Contractor (If Applicable): Argonne National Laboratory

Agency/Contractor (Performing Monitoring): Argonne National Laboratory

Report: Final Report to F.A.A. for Interagency Agreement No. DOT-FA-71 WAI-223

ABSTRACT

The report contains a complete description of the results obtained during the Airport Vicinity Air Pollution Study performed by the Argonne National Laboratory, Energy and Environmental Systems Division* for the Federal Aviation Administration under Interagency Agreement DOT-FA-71WI-223. Additional support for portions of this program was provided by the Illinois Institute for Environmental Quality.

The primary objective of the program was the development of a computer model that could be used to determine the impact of an existing or planned airport on the air quality in its vicinity.

The model development was supported by an air quality monitoring and emission activity data acquisition program. O'Hare International Airport (the busiest commercial airport in the world), which is located near Chicago, Illinois, and Orange County Airport (a busy general aviation facility), which is 40 miles south of Los Angeles, California, were selected as test sites for the program.

The activity simulation and air quality model developed during this program are discussed in detail in the text. Results of computations of air quality concentrations and comparisons with observations are presented and discussed. The results of the data acquisition program are given in the appendices.

The casual reader will find the introduction and summary sections of greatest interest. Section 3, which provides a detailed description of the air quality model and aircraft activity simulation should be of more interest to the modeling audience. The potential computer program user will find the latter portions of Section 3, which describe the computational package, of use. Those readers who are concerned primarily with

---

* Formerly Center for Environmental Studies

airport activity, emissions, and air quality data will want to refer to the appropriate appendices.

Air quality measurements for particulates, coefficient of haze, hydrocarbons, nitric oxide and other oxides of nitrogen were made at various locations at both airports using stationary and mobile samplers.

A number of airborne monitoring flights were made in the O'Hare Airport and Orange County Airport vicinity to determine if pollutant concentration gradients existed within or near the airport and the flight paths of approaching or departing aircraft. Results of these studies will be available when the final report is published in the near future.

Study Title:	VEHICLE BEHAVIOR IN AND AROUND COMPLEX SOURCES AND RELATED COMPLEX SOURCE CHARACTERISTICS SUBTASK 5 - AMUSEMENT PARKS
Sponsoring Agency:	Environmental Protection Agency
Agency/Contractor: (If Applicable)	
Agency/Contractor: (Performing Monitoring)	GEOMET, Incorporated
Report:	Task Report under EPA Contract Number 68-02-1094 Task Order Number 3

ABSTRACT

The project consisted of a task, under a task order level of effort type of contract, to "collect, analyze and integrate technical data, and develop methodologies which can be used to provide guidelines for EPA and state agencies in reviewing and evaluating proposed new or expanded complex sources." The principal technical effort involved quantitatively relating the physical characteristics of each type of complex source to automobile movements, numbers, and engine running times or speeds.

For the six complex source types which involve parking facilities (shopping centers, airports, sports stadiums, parking facilities, recreational areas, and amusement parks), the methodology involved developing the concept of combining the numbers of cars operating, with a characteristic time of operation. Both of these parameters have characteristic and peak values depending on the type of source and its physical and operational characteristics; methods of calculation of appropriate values are given, to permit use in emission and air quality estimations.

For the seventh complex source (major highways), for which parking is not a factor, a different principle was developed for relating parameters descriptive of highway traffic to highway parameters. Briefly, one approximation technique which was developed, relates operating speed to design speed and the ratio of volume demand to capacity, and then evolves this into equivalent vehicle miles travelled. A more precise technique develops traffic density for specified highway segments, from volume demand and operating speed; emission rates can then be derived from consideration of unit emission rates, operating speed, and traffic density.

The seven methodologies have been used by EPA as the basis for guidelines which relate complex source characteristics to traffic behavior parameters (described above), thence to emissions, and finally to air quality estimates.

Study Title:	AIR QUALITY ASPECTS OF THE I-66 CORRIDOR TRANSPORTATION ALTERNATES STUDY
Sponsoring Agency:	Virginia State Department of Highways
Agency/Contractor (If Applicable):	Howard, Needles, Tammen and Bergendoff Alexandria, Virginia
Agency/Contractor (Performing Monitoring):	Battelle Memorial Laboratories Columbus, Ohio
Report:	Air Quality Aspects of the I-66 Corridor Transportation Alternates Study

ABSTRACT

As indicated by the title the program is designed to evaluate several transportation alternatives in the vicinity of Washington, D. C. and the Northern Virginia area of Arlington and Fairfax counties. Air quality measurements were made at three locations along the proposed interstate corridor for approximately 10 days at each site during July and August 1973. Air quality measurements included: suspended particulates, lead, total hydrocarbons, methane, oxidants, and carbon monoxide. Wind speed and direction measurements were made at the monitoring trailer, other meteorological data was obtained from the hourly observations made at Washington National Airport. Emissions estimates were generated for grid areas in the study area and air quality estimates were made for various future time periods using different transportation alternatives. Traffic data included data from traffic counts and a home interview survey conducted in 1968. Results of the study indicate:

1) No matter which alternative is selected the air quality should improve.
2) Air quality standards will occasionally be exceeded within 300 feet of the more heavily traveled portions of I-66 or U.S. 50.
3) Of six alternatives considered the highway option is predicted to produce the maximum air pollutants emissions but each strategy considered there were locations where the air quality would be poorer than from the highway option.
4) Hydrocarbons and oxidants do exceed air quality standards however carbon monoxide is not likely to exceed standards even in the heavy traffic area of Key Bridge in the winter time.

5) Lead concentrations would exceed 2 $\mu g/m^3$ if the highway option is used and lead content of gasoline is not reduced.

Study Title:	A Carbon Monoxide Profile of a Main Artery in Mexico City
Sponsoring Agency:	
Agency/Contractor (If Applicable):	
Agency Contractor (Performing Monitoring):	
Report:	APTIC Abstract 27408 A Carbon Monoxide Profile of a Main Artery in Mexico City. Preprint Air Pollution Control Assoc., Pittsburgh, Pa., 16P., 1970. (Presented at the Air Pollution Control Association, Annual Meeting, 63rd, St. Louis, Mo., June 14-18, 1970, Paper 70-13.)

ABSTRACT

Unusually favorable conditions for the production and retention of atmospheric pollution in Mexico City include many factories with uncontrolled smoke emissions, large numbers of old, poorly tuned automobiles using low-grade, high-sulfur content fuels, many diesel motors, wide-spread trash burning, and fuel oil use for heating. Also, the city is surrounded by mountains and the natural air flow is minimum, while the altitude of 7100 feet and a large percentage of sunny days contribute to the importance of photochemical smog. Preliminary carbon monoxide concentrations sampled in November 1969 along the Paseo De La Reforma showed levels of about 45 PPM in areas where this street is about 150 feet wide. In the downtown area this street narrows to only three lanes and is about 40 feet wide, lined with 5-story buildings. Here, 100 PPM of CO was recorded, and a high of 190 PPM at the entrance of a parking garage. Traffic density was moderate at the time.

Study Title: INDOOR-OUTDOOR CARBON MONOXIDE POLLUTION STUDY

Sponsoring Agency: Environmental Protection Agency

Agency/Contractor (If Applicable): General Electric Company

Agency/Contractor (Performing Monitoring): General Electric Company

Report: Final Report to EPA under Contract No. EPA 70-77

ABSTRACT

The high value of land in some urban areas has caused some developers to build "air rights" buildings which occupy the space above highways. The object of this study was to assess the potential danger to the health of persons inhabiting the building from the pollutants generated by vehicular traffic on the highway. The study design was to obtain a large statistical data base of carbon monoxide, hydrocarbons, particulates and lead concentration inside and outside each building at different levels above the roadways and to relate those concentrations to the wind, temperature and traffic conditions. Two buildings were studied, one an "air rights" apartment building and the other a more conventional high rise apartment building in a canyon like street in midtown Manhattan. Measurements included simultaneous continuous monitoring of air pollutants, meteorological variables and traffic flow rate and velocity at each building for 5 months.

Extensive conclusions are made regarding the relationship of traffic generated pollutants to horizontal and vertical distribution both indoors and outdoors and the variability of concentrations with meteorological parameters. Among the many conclusions it is noted that carbon monoxide concentrations at both sites were traffic generated. Hydrocarbon concentrations at the air rights building were attributed to both traffic and cooking facilities, while at the conventional building painting work emissions masked any traffic related hydrocarbons. Particulate concentrations were not related to traffic at either building. Lead concentrations at the air rights building were probably due to traffic but lead concentrations at the conventional building were controlled by painting operations.

Study Title: ANALYSIS OF EXHAUST GAS INVESTIGATIONS IN PARIS

Sponsoring Agency:

Agency/Contractor (If Applicable)

Agency/Contractor (Performing Monitoring)

Report: APTIC Abstract 08568
Carbon Monoxide: Analysis of Exhaust Gas Investigations in Paris. Environ. Res., 1(2):198-2168 Oct. 1967. 3 Refs.

APTIC ABSTRACT

Using a motor car sampler, ambient air samples from Parisian streets were taken at 317 locations. The content of CO in unventilated tunnels as well as streets was measured with infrared analyzers. Yearly maps of vehicular pollution (CO levels) were drawn: differences in maps from 1959 through 1966 were found to be insignificant. In tunnels, there was a good correlation between tunnel length and CO level. A 24-hr. curve of street CO level shows CO level and traffic intensity to be directly correlated. A close correlation is found between average CO level (for 10 hrs.) and average lead content in the air, suggesting the two pollutants have the same origin. There is no correlation between CO and benzo(A)pryene levels. Automobile exhausts are responsible only for 10-20 percent of benzo(A)pyrene air pollution. A technique for reducing the CO content of exhaust gases during idling by means of a carburetor adjustment is mentioned. It is used on all police cars, with a resultant reduction of CO levels (from 97-150 ppm. to 24-38ppm.) in the police garage. In the blood of traffic policemen, tested before and after duty, carboxyhemoglobin (COHB) levels increased in nonsmokers, but may decrease in smokers, due to high levels achieved before duty. Cab drivers, when driving in traffic, tend to have higher COHB levels than workers exposed to CO, traffic policemen, or private individuals with suspected accidental CO exposure. Underground parking garages can have astonishingly high levels of CO: a new one in Paris was found to have levels above 200 ppm. for as long as 20 min. and average CO levels often reached 90-100 ppm. The adoption of air quality standards for garages is now in force in Paris.

Study Title:	AIR QUALITY ANALYSIS FOR THE MOUNT HOOD FREEWAY - I-80N IN PORTLAND, OREGON
Sponsoring Agency:	Oregon State Highway Division and U.S. DOT Federal Highway Administration
Agency/Contractor (If Applicable):	Skidmore, Owings, & Merrill
Agency/Contractor (Performing Monitoring):	Environmental Systems Laboratory
Report:	I-80N Environmental Study - Air Quality Analysis Technical Supplement

ABSTRACT

Dispersal model validation and ambient air quality measurements were executed over a 4-month period as a basis for prediction of future air quality changes due to the construction of a 5.5-mile-long, 10-lane section of Interstate 80N.

The field experiment was conducted at an urban site in Southeast Portland, Oregon. A mobile air quality laboratory and data collection system was operated at three different locations selected to characterize dispersal for the roadway geometries planned, varying from deep cut to at grade, and to typify 24-hour air quality variation. Pollutants measured included CO, NO_x, total particulate lead and reactive hydrocarbons.

Validation measurements were taken in complete data sets for all pollutants for a variety of meteorological and traffic conditions at each site, utilizing an array of up to seven monitoring locations including one upwind to characterize dispersal. CO was collected using automatic elevated bag samplers at all locations, and analyzed using gas chromatography in the van. NO_x was recorded using a movable teflon tube sample line directly connected to a wet-chemical analyzer, and particulate including lead was collected on filter paper using high volume samplers. Filters were weighted, and analyzed for elements heavier than aluminum using X-ray flourescence analysis. Wind speed, direction, and horizontal sigma were recorded. All data sets were collected in conjunction with simultaneous ambient pollutant monitoring bidirectional traffic speed and volume, vehicle mix, temperature, cloud cover and precipitation information being recorded.

Ambient background concentrations or all pollutants were collected continuously 24 hours a day along with meteorological data at the validation sites. In addition, automatically timed remote samplers at 10 locations simultaneously throughout the roadway corridor collected CO over periods of up to 2 hours in bags, at pre-set intervals through the day. These were collected and analyzed at the mobile laboratory.

All data was normalized, calibrated, and reduced by computer. Outputs included hourly, 8- and 24-hour averages, and a graphical presentation of varying pollutant levels and meteorological parameters.

Study Title: AIR QUALITY IMPACT STUDY FOR PROPOSED HIGHWAY WIDENING NEAR OJAI

Sponsoring Agency: California DOT (District 7)

Agency/Contractor (If Applicable:

Agency/Contractor (Performing Monitoring): Stanford Research Institute

Report: To be prepared in summer of 1974

ABSTRACT

Stanford Research Institute is undertaking a research project to analyze the potential effects on air quality that might be associated with a proposed highway widening and realignment in the Ojai area of Ventura County - specifically Routes 33 and 150 from the end of Route 33 Freeway at Casitas Springs Road to Maricopa Road in the City of Ojai. This research project is funded by the California Department of Transportation, District 7.

The objectives of this study are as follows:

1. Measure and characterize the current air quality and meteorology in the Ojai area.
2. Predict future air quality near the roadway and area-wide, with and without the highway improvement, for the years 1980 and 2000.
3. Assess the effects of current air quality on local agriculture by means of site surveys, and predict future effects with and without the proposed highway improvement for the years 1980 and 2000.

Air quality measurements will include nitric oxide, nitrogen dioxide, nitrogen oxides, ozone, carbon monoxide, methane, total hydrocarbons suspended particulates, lead, and atmospheric turbidity.

The measurement program will consist of three phases. Two area-wide measurement phases will be conducted - the first during the smog season when visibility reduction occurs, and the second during late fall when pollutants are present but visible smog is not evident. The third measurement phase will determine pollutant concentrations near the roadway area where the proposed improvement would occur.

During the area-wide measurement phases, a total of six sites will be located throughout the Ojai Valley to measure winds and to monitor

pollutant levels by means of either collected air samples or continuous measurements. Air samples will be collected at five outlying stations and returned for measurement of pollutant levels to a central air monitoring station to be established near Ojai. An instrumented light aircraft will also be used on selected days to obtain measurements at upper levels. Winds at these levels will be obtained regularly by means of small weather balloons.

Once the measurement program has been completed, the data will be analyzed and assembled with other available data on current air quality, meteorology, stationary source pollutant emissions, and traffic patterns and volumes for the region. Using this data base, current air quality in and around the Ojai area will be simulated numerically using a computer. Predictions of future air quality will be made by using traffic projections for the years 1980 and 2000 as inputs to the computer simulation model. In addition, the influence of alternative forms of transportation such as bus or rail transit systems on air quality will be modeled. Estimates will also be made of the effects of predicted future air quality on local agriculture.

Study Title:	A STATEMENT ON THE EXPECTED IMPACT OF INDIRECT SOURCES ON AMBIENT AIR QUALITY
Sponsoring Agency:	Texas Air Control Board
Agency/Contractor (If Applicable):	
Agency/Contractor (Performing Monitoring):	Texas Air Control Board
Report:	

ABSTRACT

The Texas Air Control Board has conducted a series of studies of carbon monoxide concentrations near highways, roads and major intersections in Fort Worth and Dallas, Houston, San Antonio, and the Houston Ship Channel area. In Fort Worth and Dallas, 55 sampling sites were selected at major intersections and carbon monoxide was measured for five minutes at each site. Traffic count data are available from some sites and estimates of traffic are made where actual counts were not made. Five minute average CO values in Fort Worth ranged from 1.5 to 8.0 ppm. In Dallas the CO values ranged from 3.5 to 16.0 ppm. Data from studies in San Antonio, Houston and the Houston Ship Channel are given. The data from those studies support the findings in Dallas-Fort Worth that low concentrations of CO are found throughout those cities. CO measurements in Houston were made from a roving van with the results showing 90 percent of the observations made, which included measurements on high traffic volume freeways and interchanges which have traffic volumes as high as 202,000 vehicles per day, were below 10 ppm.

It is anticipated, by the Texas Air Control Board that the findings of the highways and intersections studies can be applied to other indirect sources. The conclusions made in this paper were:

1. CO levels are uniform across urban areas and are well below the national ambient air quality standard.
2. No significant consistent correlation can be made between traffic count on the highways and intersections and measured CO concentrations.
3. Ambient CO levels are not significantly influenced by traffic on highways beyond a short horizontal distance from the highway due to the rapid dispersion of the pollutant.

Study Title:	AN AIR QUALITY ASSESSMENT FOR 148th STREET, BELLEVUE, WASHINGTON
Sponsoring Agency:	
Agency/Contractor (If Applicable):	CH_2M Hill and Associates
Agency/Contractor (Performing Monitoring):	Northwest Environmental Technology Laboratories, Inc.
Report:	NETL No. 38-73-038

ABSTRACT

The study conducted was to provide an assessment of the impact of increasing traffic capacity on the air quality in the vicinity of 148th Street in Bellevue. The air quality assessment required evaluation of pollutant contributions from several sources, e.g., background levels from homes, businesses, and vehicles on local streets. Additional contributions from vehicles using parking lots at two shopping centers are considered separately. Carbon monoxide concentrations and meteorological data were collected over a 16-day period in December 1973. Continuous air quality measurements were made at two locations for eight days at each site.

Results of the CO monitoring showed that under constant meteorological conditions the CO concentrations built up as a result of the morning traffic peak tended to persist throughout the day and only a slight additional increase in the evening due to the peak evening traffic. There was little difference between the 1-hour maximum concentrations and 8-hour average concentrations. Air quality standards were not exceeded during the monitoring period.

Traffic data is taken from projected road design capacity. Computer modelling is used to estimate air quality conditions through the year 1990.

Study Title:	I-205 AIR MONITORING DATA SUPPLEMENT TO FINAL ENVIRONMENTAL IMPACT STATEMENT
Sponsoring Agency:	State of Oregon, Department of Transportation, Highway Division
Agency/Contractor (If Applicable):	
Agency/Contractor (Performing Monitoring):	Environmental Section, Highway Division, Oregon Department of Transportation

ABSTRACT

The assessment of the impact of the proposed I-205 Freeway on air quality has been studied in a three part program. The three parts of the program are: (1) Prediction of future air quality, (2) Measurement of existing air quality - long term, and (3) Measurement of air quality - short term (bag sampling). Part I has been completed and reported. Part II is an ongoing program for continuous long-term monitoring of transportation-related pollutants. This part of the program includes a mobile air monitoring trailer which is parked at a site near the I-205 corridor and operated for a three-week period once every three months for a full year.

The monitoring program will obtain information on carbon monoxide, nitric oxide, nitrogen dioxide, ozone, total hydrocarbons, reactive hydrocarbons, methane, suspended particulates and lead particulates. Meteorological parameters will be recorded also. Data will be recorded continuously on a 24-hour basis and stored on a magnetic tape.

Part III of the program has been completed and reported. Part III included a short-term simultaneous bag sampling program designed to determine the instantaneous carbon monoxide background levels over large areas of a freeway corridor. Two meteorological stations were set up to supplement the data collected for the immediate areas of concern.

Information for this summary was taken from the report made for the third part of the program. Results of the whole measuring program are not furnished. Data summaries for Part III are presented which indicate uniform results were obtained from the wide area sampled when care was taken in selecting the sample sites.

Study Title: ROSTOV-ON-DON ATMOSPHERIC AIR POLLUTION WITH AUTO-TRAFFIC EXHAUST CARBON MONOXIDE

Sponsoring Agency: USSR

Agency/Contractor (If Applicable):

Agency/Contractor (Performing Monitoring):

Report: CFSTI: 63-11570 (Document temporarily out of stock - Abstract below is APTIC Abstract 21076)

ABSTRACT

Air pollution from automobile exhaust gases was studied at four main highways at five observation points located where automobile traffic was heavy. Air samples were collected through the months of April-September during the hours from 8 a.m. - 9 p.m. and through the months of October-November during the hours of 8 a.m. - 5 p.m. Samples were collected into liter flasks by the salt solution-negative-pressure method for 1-2 minutes at 1.5 m above the ground. Three samples were collected at each point: one on the highway itself, one on the sidewalk, and one near trees or bushes. With the aid of a gas analyzer, 1280 samples were analyzed. The results clearly indicated that the city air basin was heavily polluted with carbon monoxide and concentrations ranged between 1.5-80.0 mg/cu m. Approximately 87.7 percent of the samples exceeded the maximum allowable concentration. Generally, the CO concentration varied proportionately with the number of passing automobiles and also with the terrain and meteorological conditions. Carbon monoxide concentrations were higher in the summer and varied very little between the highway, sidewalk, and trees. Samples collected at the wider highways contained lower CO concentrations than did samples collected at narrower highways, probably due to more intensive air circulation and ventilatio

Study Title: AIR QUALITY ANALYSIS OF ALTERNATIVE HIGHWAY OPTIONS IN THE CLOVERDALE AND HOPLAND AREA

Sponsoring Agency: California Department of Highways, District 4

Agency/Contractor (If Applicable):

Agency/Contractor (Performing Monitoring): Environmental Systems Laboratory

Report: ESL-ET48, June 1973

ABSTRACT

This air quality and meteorology study for the Highway 101 bypass around Cloverdale was sponsored by the California Department of Highways District 4. A validation experiment using automatic collection of air samples at a height of 1-1/2 meters at distances of 8, 16, 32, 64, 128 meters on both sides of an open roadway as well as different locations in downtown Cloverdale was a major part of this effort. Various meteorological and traffic conditions were examined including calm conditions and winds parallel to the roadway. Experiments included validation and reliability measurements. Approximately 1000 air bags were collected in order to validate a dispersal model from the roadway in the urban community and flat terrain. Ambient concentrations of carbon monoxide, lead, oxidants, and nitrogen dioxide were measured for several months.

The influence of valley drainage was found to effect pollution dispersal. The influence of drainage was measured by correlating the wind direction at stations near the bottom of the valley walls to concentrations of CO in the center of Cloverdale. The extreme stagnation from drainage flows at the bottom of the valley results in accumulation of CO from vehicles in the atmosphere.

The results of measurements near the roadway and ambient stations were used to describe the community exposure to degraded air under build and no build strategies. This evaluation will be a part of the Department of Highway's Environmental Impact Statement regarding the proposed construction.

Study Title:	AIR QUALITY ANALYSIS FOR THE I-505 CORRIDOR PORTLAND, OREGON
Sponsoring Agency:	Oregon State Highway Division/Federal Highway Administration
Agency/Contractor (If Applicable):	
Agency/Contractor (Performing Monitoring):	Environmental Systems Laboratory, Inc.
Report:	ESL-ET44, September 1973

ABSTRACT

Validation measurements to calibrate air pollution dispersal models for elevated, hillslope, and at grade roadway geometries were conducted along with ambient air quality monitoring in the corridor area for the planned I-505 freeway in Northwest Portland, Oregon. Measurements for CO, NO_x, total particulate and particulate lead were made over a period of approximately 3 months.

Measurements of pollutant dispersion was accomplished at three sites utilizing the ESL Mobile Air Quality Laboratory. An array of up to seven sensor locations extending to 1000 feet from the roadway was used to collect profile data for all pollutants. Analysis of samples was by gas chromatography, liquid chemical analyzer for NO_x, and by atomic excited X-ray flourescence. Wind speed, direction, and horizontal sigma were measured with a sensitive propeller anemometer vane. For data sets, traffic speed, direction and vehicle mix in both directions, temperature, cloud cover, and precipitation information were recorded.

Continuous 24-hour ambient background pollutant concentrations were collected along with meteorological data. Ten automatic timed samplers simultaneously collected bays of ambient air for CO measurement at various locations spaced through the corridor, at pre-set intervals through the day.

This study was the basis for a Draft Environmental Impact Statement.

Graphical presentation of air quality data, meteorological data and comparisons of dispersal model predictions with experimental data are presented.

Study Title: AIR POLLUTION IMPACT OF PROPOSED WIDENING OF THE NEW JERSEY TURNPIKE BETWEEN EXITS NINE AND TEN

Sponsoring Agency: New Jersey Department of Transportation

Agency/Contractor (If Applicable):

Agency/Contractor (Performing Monitoring): Environmental Systems Laboratory
Sunnyvale, California

Report: ESL-ET32 March 1972

ABSTRACT

Air and noise pollution impact to the predominantly residential community of East Brunswick, New Jersey, was analyzed for widening and no widening alternatives of this major highway. Predictions were made using expected traffic volumes and vehicle emissions for the year 1990. Air pollution measurements of nitrogen oxides with meteorological measurements and traffic counts were made in order to determine the present air quality and study the manner in which air pollutants disperse near the highway. As a result a mathematical model describing the dispersal of vehicle emissions into neighboring land was verified; this model was used to predict future community air quality for oxides of nitrogen, carbon monoxide and hydrocarbons.

3 - HIGHWAY

Study Title:	WEST SIDE HIGHWAY PROJECT (INTERSTATE ROUTE CONNECTION 518, WEST SIDE HIGHWAY FROM THE BATTERY TO 52nd STREET)
Sponsoring Agency:	New York State Department of Transportation
Agency/Contractor (If Applicable):	Parson, Brinkerhoff, Quade and Douglas New York City
Agency/Contractor (Performing Monitoring):	General Electric Company, Reentry and Environmental Systems Division, Philadelphia
Report:	(A draft EIS is expected by June 1974)

ABSTRACT

The technical air quality study is reported to be patterned on a previous study "Study of Air Pollution Aspects of Various Roadway Configurations", General Electric, September 1973 (NTIS No. PB-211-235). Pollutants measured were carbon monoxide, nitrogen oxides, total hydrocarbons and methane, particulates, and particulate lead. There were four primary measurement sites on the highway and 15 secondary sites in the region which would be most affected by the West Side Highway Project. Meteorological measurements consisted of a continuous recording of wind speed and direction and air temperature. Traffic measurements included volume and speed on each lane of the highway made. A draft environmental impact statement is expected to be published by June 1974.

Study Title: ENVIRONMENTAL IMPACT OF THE PROPOSED I-287 IN BERGEN AND PASSAIC COUNTIES

Sponsoring Agency: Local Municipalities in Bergen and Passaic Counties, New Jersey

Agency/Contractor (If Applicable):

Agency/Contractor (Performing Monitoring): Environmental Systems Laboratory
Sunnyvale, California

Report: ESL-ET 42, February 1973

ABSTRACT

The study was sponsored by the various municipalities influenced by the corridor decision of Interstate 287. The study involved measurements of ambient air pollution levels as well as the pollution dispersal characteristics of highways. Pollutants measured were carbon monoxide and nitrogen oxides. Meteorological and traffic measurements were also made. The relative exposure to the community of degraded air was evaluated for several alternate corridor decisions and for alternatives generated by the study. In addition to the air quality considerations, community noise exposure and ecological impacts were examined in detail for each alternative.

Study Title: AIR QUALITY ANALYSIS OF THE WIDENING OF I-80 IN THE VICINITY OF CARGUINEZ, CALIFORNIA

Sponsoring Agency: California Department of Highways

Agency/Contractor (If Applicable):

Agency/Contractor (Performing Monitoring): Environmental Systems Laboratory
Sunnyvale, California

Report: ESL-ET74 (to be published in 1974)

ABSTRACT

In a program for the California Department of Highways, ESL carried out a program to validate both highway and area source dispersal models. Four sites near different characteristics of Interstate 80 north of Berkeley, California were chosen for the highway validation. Air quality at these sites were monitored at several distances from the roadway simultaneously; concurrent traffic counts and meteorology were measured. Pollutants measured were carbon monoxide, total and non-methane hydrocarbons, particulates, nitrogen oxides, and oxidants.

Four ambient CO monitoring sites at the perimeter of the study area were also monitored. This information was supplemented by extensive bag sampling for CO throughout the area.

The information gained during this study was input to a least squares validation of the ESL vertical strip model and the Gifford-Hamma area source model supplementing and extending previous ESL Model validation in Oregon, California, New Jersey and New York. Predictions based on these models were also incorporated as the air quality impact study for the environmental impact statement.

Of particular importance in this study was the meteorological monitoring. The meteorological field experiments measured thermal gradients, wind shear, and turbulence variation with height as input to the subsequent analysis of the relationship between these gradients and the meteorological variables of air temperature, relative humidity, solar radiation and cloud cover. The instrumentation used consisted of arrays of UVW anemometers distributed at various heights and locations and thermocouple arrays as well as the instrumentation for measuring solar radiation. For this program ESL developed a special data acquisition unit which permitted sampling intervals as short as one second in order to collect the small time scale turbulence and temperature fluctuations. The measurements were used to produce magnetic tape in the field in an ESL mobile laboratory.

Wind and temperature data were reduced to the form of mean values and standard deviations over various time averaging periods. Computer codes were developed to test relationships among the measured variables and to compute the Richardson's Number to understand the impact of measured variables upon stability of the boundary layer. The data were analyzed to study spatial and temporal variation of the gradient parameters and applications were made to trace the microscale air flow field over irregular terrain.

3 - HIGHWAY

Study Title: . . . HIGHWAY AIR POLLUTION DISPERSAL USING TRACER GAS . . .

Sponsoring Agency: Environmental Protection Agency

Agency/Contractor (If Applicable):

Agency Contractor (Performing Monitoring): Environmental Systems Laboratory
Sunnyvale, California

Report:

ABSTRACT

ESL is currently under contract to the United States Environmental Protection Agency to perform extensive field measurements in order to characterize air pollution dispersal from highways. This very complex measurement and data reduction program, which will provide definitive data to public and private air quality modeling institutions throughout the country, is being performed in Santa Clara County, California. The program features the detection of controlled releases of sulfur hexafloride along with dispersal measurements of carbon monoxide; four sites near distinctly different single roadway types are being instrumented. Simultaneous air samples are taken at 10 spatially distinct locations and meteorological data at six simultaneous stations at each site. The meteorological data includes U.V.W. sensors at each station. Simultaneous measurements of wind shear, lapse rate, turbulence and other meteorological data were made at six spatially separated locations.

Study Title: AIR, NOISE, AND TRAFFIC ENVIRONMENTAL IMPACT ASSOCIATED WITH THE DUMBARTON BRIDGE REPLACEMENT

Sponsoring Agency: California Division of Bay Toll Crossings

Agency/Contractor (If Applicable):

Agency/Contractor (Performing Monitoring): Environmental Systems Laboratory
Sunnyvale, California

Report: ESL-ET39 July 1972

ABSTRACT

This initial study and its follow-on examined the air pollution, traffic, and noise impact to residential areas regarding the replacement of the Dumbarton Bridge; this highway would collect traffic diverted from the Dumbarton Bridge in the event of bridge replacement. Nitrogen dioxide, oxidant, and carbon monoxide concentrations were measured. Meteorological measurements and traffic measurements were also made. Validation experiments on carbon monoxide were performed in the vicinity of Highway 17.

The study indicated the traffic conditions, air quality and noise climate concerning the replacement. In particular, the relative community exposure to degraded air in the vicinity of the proposed western feeders to the bridge was evaluated for different feeder route plans. In addition, the study suggested a new alternate feeder route plan which would satisfy all of the air quality and traffic concerns.

Study Title:	VALIDATION AND APPLICATIONS OF AN URBAN DIFFUSION MODEL FOR VEHICULAR POLLUTANTS
Sponsoring Agency:	Coordinating Research Council and Environmental Protection Agency
Agency/Contractor (If Applicable):	Stanford Research Institute
Agency/Contracror (Performing Monitoring):	Stanford Research Institute
Report:	Atmospheric Environment, Permagon Press, Vol. 7, pp. 603-618, 1973

ABSTRACT

A practical, multipurpose urban diffusion model (APRAC-1A) has been developed and evaluated for predicting concentrations of inert, vehicle-generated pollutants. The model requires only routinely available meteorological and traffic data to give the following outputs: (1) areal concentration isopleths, (2) sequential hourly point values, and (3) frequency distributions. An extensive field experiment was conducted in San Jose to evaluate and refine all components of the model. A street effects submodel was developed to account for the high concentrations and large gradients observed in urban street canyons. Results are presented from a second experimental program conducted in St. Louis to further evaluate the performance of the model. Predicted and observed concentrations of carbon monoxide (CO) in St. Louis differ by root-mean-square values of the order of 3 ppm (parts per million), while frequency distributions of hourly concentrations are given within 2-3ppm. Along-street observations of CO concentrations show variations generally less than 1ppm.

In San Jose, measurements of CO were made at 5 levels on both sides of the street and at 5 points across each street. Two streets were studied. Three component winds were measured at roof level and at 4.5m. level on both sides of the street. In St. Louis, airport meteorological data were used and State Highway Department traffic data was used. CO data was collected on four streets.

Study Title: STUDY OF AIR POLLUTION ASPECTS OF VARIOUS ROADWAY CONFIGURATIONS

Sponsoring Agency: New York City Department of Air Resources and Environmental Protection Agency, Air Pollution Control Office and United States Bureau of Public Roads, New York Division Office

Agency/Contractor (If Applicable):

Agency/Contractor (Performing Monitoring): General Electric Co., Reentry and Environmental Systems Division, Philadelphia.

Report: NTIS No. PB 211 235, September 1971

ABSTRACT

The study was undertaken to ascertain the current air quality in the immediate vicinity of various urban roadway configurations, to determine how the selected urban roadway configurations aid or hinder the diffusion of the pollutants emitted by urban traffic, and to develop mathematical relationships between traffic, traffic speed, pollutant concentration, meteorological parameters and roadway configuration. There were 10 typical sites selected for monitoring. These sites were representative of open-cut roadways, tunnels, cantilever covered roadways, open roadways, and intermittantly covered roadways. Carbon monoxide was measured continuously at 16 different locations at each site. In addition a pooled hydrocarbon measurement was made from the 16 locations, and a particulate and trace metal measurement was made. Simultaneous meteorological measurements were recorded at two locations at each site, one location was usually on the median of the road being studied, the other location was at a higher location and away from obstructions to record general wind conditions in the area. The recorded information was wind speed, azimuth, elevation, azimuth sigma (standard deviation) and elevation sigma. Traffic volumes were obtained with pneumatic tube counters and multi-axle vehicles were classified as gasoline or diesel from visual observation. Traffic speeds were also recorded from stopwatch, radar, and pneumatic tube observations. At five sites indoor/outdoor carbon monoxide measurements were made. The indoor monitors were located in air rights buildings or nearby buildings. The report presents measured horizontal and vertical concentration profiles and a detailed discussion of the effects observed at each of the 10 sites.

Study Title:	Not Available
Sponsoring Agency:	U. S. DOT, Federal Highways Administration
Agency/Contractor (If Applicable):	
Agency/Contractor (Performing Monitoring):	California Department of Highways
Report:	First report of progress not due at this time.

ABSTRACT

There are no reports written regarding this major study which is just getting underway in March 1974. The scope and intent of this study are significant enough to warrant the attention of all those who are concerned with highway models. The information regarding this study is not complete but some of the salient features of the program are noted to inform the reader that a study of this magnitude is underway. The purpose of the study is to gather and record enough information to verify any mesoscale or microscale models available. Measurements of carbon monoxide, nitrogen dioxide, particulates and hydrocarbons will be made at different roadway configurations where the roadbed is below, above and at grade. Meteorological data will include 2 and 3 directional winds, 2 levels of temperature and relative humidity. Traffic data will be recorded using traffic radar and automatic traffic counters. Three complete mobile monitoring laboratories are being assembled in the early part of 1974 and will be in the field for monitoring work as soon as they are ready. The field data will be assembled for input to various dispersion models for model verification.

Under a separate study California Department of Highways is studying highway related pollutants with a large scale model which will allow modeling for corridor scale studies - and will include a photochemical model for study of oxidants. The model will be calibrated for Sacramento then used in other cities to verify its usefulness.

Study Title: AIR QUALITY MANUAL VOL. VIII

Sponsoring Agency: U.S. DOT, Federal Highways Administration

Agency/Contractor (If Applicable):

Agency/Contractor (Performing Monitoring):

Report: Final Report to DOT on Contract DOT-FH-11-7730

ABSTRACT

This publication is included in this group of studies to insure reference to this major piece of work accomplished by the California Division of Highways. The series of publications is available from NTIS. The foreward to Volume VIII is reproduced to introduce the complete set of publications produced.

FOREWORD

A number of studies must be completed prior to the writing of an Environmental Impact Statement for a highway project. One of these studies is concerned with the gathering of field data, analysis of such data, and writing an air quality report.

The California Division of Highways has embarked on a program of equipping and training district personnel to prepare air quality reports. This required a two-week training course and the preparation of air quality manuals to be used as guides in the gathering of field data, analysis of results, and writing the report.

This volume is the first in a series of eight volumes, the titles of which follows:

1. Meteorology and its Influence on the Dispersion of Pollutants from Highway Line Sources.
2. Motor Vehicle Emission Factors for Estimates of Highway Impact on Air Quality.
3. Traffic Information Requirements for Estimates of Highway Impact on Air Quality.
4. Mathematical Approach to Estimating Highway Impact on Air Quality.
5. Appendix to Volume 4.
6. Analysis of Ambient Air Quality for Highway Environmental Projects.
7. A Method for Analyzing and Reporting Highway Impact on Air Quality.

8. Synthesis of Information on Highway Transportation and Air Quality.

The material presented in these volumes is subject to change as further research provides information. The following items are not discussed or, if presented, are subject to care in the interpretation of results.

1. There is no accepted emission factors for oxides of nitrogen relating emissions to speed.
2. There are no statistically validated photochemical models for different meteorological conditions which will permit calculations of oxidant formed downwind from a line source.
3. Further research is required to fully validate model calculations when winds blow parallel to the line source.

Study Title:	VEHICLE BEHAVIOR IN AND AROUND COMPLEX SOURCES AND RELATED COMPLEX SOURCE CHARACTERISTICS SUBTASK 6 - MAJOR HIGHWAYS
Sponsoring Agency:	Environmental Protection Agency
Agency/Contractor: (If Applicable)	
Agency/Contractor: (Performing Monitoring)	GEOMET, Incorporated
Report:	Task Report under EPA Contract Number 68-02-1094 Task Order Number 3

ABSTRACT

The project consisted of a task, under a task order level of effort type of contract, to "collect, analyze and integrate technical data, and develop methodologies which can be used to provide guidelines for EPA and state agencies in reviewing and evaluating proposed new or expanded complex sources." The principal technical effort involved quantitatively relating the physical characteristics of each type of complex source to automobile movements, numbers, and engine running times or speeds.

For the six complex source types which involve parking facilities (shopping centers, airports, sports stadiums, parking facilities, recreational areas, and amusement parks), the methodology involved developing the concept of combining the numbers of cars operating, with a characteristic time of operation. Both of these parameters have characteristic and peak values depending on the type of source and its physical and operational characteristics; methods of calculation of appropriate values are given, to permit use in emission and air quality estimations.

For the seventh complex source (major highways), for which parking is not a factor, a different principle was developed for relating parameters descriptive of highway traffic to highway parameters. Briefly, one approximation technique which was developed, relates operating speed to design speed and the ratio of volume demand to capacity, and then evolves this into equivalent vehicle miles travelled. A more precise technique develops traffic density for specified highway segments, from volume demand and operating speed; emission rates can then be derived from consideration of unit emission rates, operating speed, and traffic density.

The seven methodologies have been used by EPA as the basis for guidelines which relate complex source characteristics to traffic behavior parameters (described above), thence to emissions, and finally to air quality estimates.

Study Title:	ENVIRONMENTAL ANALYSES AND REPORT FOR ROUTE 18 FREEWAY EXTENSION, CITY OF NEW BRUNSWICK AND PISCATAWAY TOWNSHIP, MIDDLESEX COUNTY, NEW JERSEY
Sponsoring Agency:	New Jersey State Department of Transportation
Agency/Contractor:	King and Gavares, Consulting Engineers New York City
Agency/Contractor (Performing Monitoring):	General Electric Co., Reentry and Environmental Systems Division, Philadelphia, Pa.
Report:	July 1972

ABSTRACT

The air monitoring study was undertaken to assess the ambient air quality in the vicinity of a planned four-lane divided highway. The measurements were made on George Street parallel to the proposed route. Four carbon Monoxide monitors were used; two were located in dormatories and two were located outside. Wind speed, wind direction, and traffic were measured.

Study Title:	VEHICLE BEHAVIOR IN AND AROUND COMPLEX SOURCES AND RELATED COMPLEX SOURCE CHARACTERISTICS SUBTASK 4 - PARKING FACILITIES
Sponsoring Agency:	Environmental Protection Agency
Agency/Contractor: (If Applicable)	
Agency/Contractor: (Performing Monitoring)	GEOMET, Incorporated
Report:	Task Report under EPA Contract Number 68-02-1094

ABSTRACT

The project consisted of a task, under a task order level of effort type of contract, to "collect, analyze and integrate technical data, and develop methodologies which can be used to provide guidelines for EPA and state agencies in reviewing and evaluating proposed new or expanded complex sources." The principal technical effort involved quantitatively relating the physical characteristics of each type of complex source to automobile movements, numbers, and engine running times or speeds.

For the six complex source types which involve parking facilities (shopping centers, airports, sports stadiums, parking facilities, recreational areas, and amusement parks), the methodology involved developing the concept of combining the numbers of cars operating, with a characteristic time of operation. Both of these parameters have characteristic and peak values depending on the type of source and its physical and operational characteristics; methods of calculation of appropriate values are given, to permit use in emission and air quality estimations.

For the seventh complex source (major highways), for which parking is not a factor, a different principle was developed for relating parameters descriptive of highway traffic to highway parameters. Briefly, one approximation technique which was developed, relates operating speed to design speed and the ratio of volume demand to capacity, and then evolves this into equivalent vehicle miles travelled. A more precise technique develops traffic density for specified highway segments, from volume demand and operating speed; emission rates can then be derived from consideration of unit emission rates, operating speed, and traffic density.

The seven methodologies have been used by EPA as the basis for guidelines which relate complex source characteristics to traffic behavior parameters (described above), thence to emissions, and finally to air quality estimates.

Study Title: ENVIRONMENTAL IMPACT REPORT ON THE NORTH BAYSHORE REDEVELOPMENT COMMERCIAL RECREATIONAL PARK

Sponsoring Agency: Private

Agency/Contractor (If Applicable):

Agency/Contractor (Performing Monitoring): Environmental Systems Laboratory
Sunnyvale, California

Report: ESL-ET31 December 1971

ABSTRACT

The Environmental Systems Laboratory prepared an environmental impact statement of a proposed Commercial and Recreational Redevelopment Project for the North Baylands area of Mountain View, California. The analysis conformed to the guidelines set forth by the National Environmental Quality Act as well as the California Environmental Quality Act. Both ambient air quality and noise levels were measured at several sites in the project area. Pollutants measured were carbon monoxide and nitrogen oxides. Meteorological measurements and traffic measurements were made. The analysis examined, in detail, the implications of the project to the community air quality and noise levels.

Study Title:	VEHICLE BEHAVIOR IN AND AROUND COMPLEX SOURCES AND RELATED COMPLEX SOURCE CHARACTERISTICS SUBTASK 7 - RECREATION AREAS
Sponsoring Agency:	Environmental Protection Agency
Agency/Contractor: (If Applicable)	
Agency/Contractor: (Performing Monitoring)	GEOMET, Incorporated
Report:	Task Report under EPA Contract Number 68-02-1094 Task Order Number 3

ABSTRACT

The project consisted of a task, under a task order level of effort type of contract, to "collect, analyze and integrate technical data, and develop methodologies which can be used to provide guidelines for EPA and state agencies in reviewing and evaluating proposed new or expanded complex sources." The principal technical effort involved quantitatively relating the physical characteristics of each type of complex source to automobile movements, numbers, and engine running times or speeds.

For the six complex source types which involve parking facilities (shopping centers, airports, sports stadiums, parking facilities, recreational areas, and amusement parks), the methodology involved developing the concept of combining the numbers of cars operating, with a characteristic time of operation. Both of these parameters have characteristic and peak values depending on the type of source and its physical and operational characteristics; methods of calculation of appropriate values are given, to permit use in emission and air quality estimations.

For the seventh complex source (major highways), for which parking is not a factor, a different principle was developed for relating parameters descriptive of highway traffic to highway parameters. Briefly, one approximation technique which was developed, relates operating speed to design speed and the ratio of volume demand to capacity, and then evolves this into equivalent vehicle miles travelled. A more precise technique develops traffic density for specified highway segments, from volume demand and operating speed; emission rates can then be derived from consideration of unit emission rates, operating speed, and traffic density.

The seven methodologies have been used by EPA as the basis for guidelines which relate complex source characteristics to traffic behavior parameters (described above), thence to emissions, and finally to air quality estimates.

6 - SHOPPING CENTER

Study Title: PRELIMINARY ENVIRONMENTAL ASSESSMENT OF THE HUNT VALLEY SHOPPING CENTER IN BALTIMORE COUNTY

Sponsoring Agency: Private

Agency/Contractor (If Applicable):

Agency/Contractor (Performing Monitoring): Environmental Systems Laboratory
Sunnyvale, California

Report: ESL-ET69, November 1973

ABSTRACT

An environmental analysis was conducted for the Arthur Fischer Corporation, the developer of a regional shopping center in Baltimore County, Maryland. The principal issues investigated were impact on air, noise, and water. Air and noise issues were generated by the vehicular traffic attracted to the facility.

Special attention was paid to assessing the present air quality characteristics of the area and ascertaining what type of increment on air pollution would be caused by the traffic patterns generated at peak hours and the most critical eight hour period of operation of the center. Air quality, meteorology, traffic, and noise were monitored at a fixed station on site. Pollutants measured were carbon monoxide and oxidants. The air quality and noise measurement was supplemented by sampling meteorological conditions near the major roadway facilities feeding the center. This assessment allowed predictions of air quality to be made using actual on-site meteorological data rather than an extrapolation from the nearest airport.

Study Title:	VALIDATION STUDY OF AN APPROACH FOR EVALUATING THE IMPACT OF A SHOPPING CENTER ON AMBIENT CARBON MONOXIDE CONCENTRATIONS
Sponsoring Agency:	Environmental Protection Agency, Office of Air Quality Planning and Standards, Monitoring and Data Analyses Division, Sources, Receptors, and Analyses Branch
Agency/Contractor (If Applicable):	
Agency/Contractor (Performing Monitoring):	G.C.A. Corporation
Report:	A draft report is expected in March 1974

ABSTRACT

The purpose of the study was to attempt to validate the previously developed approach proposed by EPA for estimating the peak impact of a regional shopping center on ambient air quality in its immediate vicinity. The study was conducted at a large shopping mall in the two weeks preceding Christmas, 1973. Five continuous carbon monoxide analyzers were used, one located near the major gate and the others in selected locations within the parking lot. Meteorological measurements recorded included a continuous recording of wind speed and direction, surface temperature, and visual indications of stability such as cloud cover. Traffic measurements included continuous counting devices at all entrances and exits and spot checks of running times during congested and minimal use periods.

Preliminary reports of the results of the monitoring indicate that the concentrations of carbon monoxide were highest near gates with a highest recorded value of 30 ppm. Concentrations within the lot were reported to be always within the National Ambient Air Quality Standards. A draft report is expected in March 1974.

Study Title:	. . . AIR QUALITY IMPACT OF LARGE TRAFFIC GENERATING COMPLEX SOURCES . . .
Sponsoring Agency:	County of Milwaukee, Wisconsin
Agency/Contractor (If Applicable):	
Agency/Contractor (Performing Monitoring):	County of Milwaukee, Department of Air Quality Control
Report:	Interoffice Memorandum, September 21, 1973

ABSTRACT

The County of Milwaukee is faced with the question of where to locate a new sports arena. Impact on air quality is one of the criterion which will be considered in the decision making process. In order to evaluate the potential impact the County Department of Air Quality Control made on-site carbon monoxide surveys in May and June 1973 at:

a. The Milwaukee County Stadium
b. State Fair Park
c. Lakefront Parking Area
d. Southridge Shopping Center

The observations made indicated neither the 1 hour or the 8 hour standards were exceeded at any of the four sites. Sampling was done during peak Friday afternoon and evening shopping hours; on a Sunday afternoon when 10,366 arrived at the State Fair Park. Meteorological data was not collected Carbon monoxide detector tubes were used which provided a six minute sample time. Traffic data is provided.

Study Title: . . . RALEIGH, NORTH CAROLINA SHOPPING CENTER AIR QUALITY MONITORING STUDY . . .

Sponsoring Agency: Environmental Protection Agency, Office of Air Quality Planning and Standards, Monitoring and Data Analysis Division

Agency/Contractor (If Applicable):

Agency/Contractor (Performing Monitoring): Research Triangle Institute
Research Triangle Park, Durham, N. C.

Report:

ABSTRACT

The study of carbon monoxide concentrations related to shopping centers was conducted in two phases. Phase I (January-February 1973) involved preliminary monitoring of carbon monoxide concentrations at five separate locations. Wind speed and direction were measured at one location in each center. Traffic counts were obtained at each location.

Phase II (February-March 1973) concentrated on one shopping center. Carbon monoxide concentrations were measured at four locations within the shopping center parking area and one location adjacent to a nearby highway. Maximum hourly concentrations and maximum eight hour CO concentrations are plotted for each of the five sites. Daily traffic counts were taken at four entrances to the shopping center and in one traffic lane within the center. No meteorological data is presented.

6 - SHOPPING CENTER

Study Title: A MONITORING PROJECT TO EXAMINE THE RELATIONSHIP BETWEEN CO CONCENTRATIONS AND VEHICULAR ACTIVITY ASSOCIATED WITH COMPLEX SOURCES

Sponsoring Agency: Illinois, Division of Air Pollution Control

Agency/Contractor (If Applicable):

Agency/Contractor (Performing Monitoring): Illinois, Division of Air Pollution Control (DAPC)

Report: Information on Proposed "Complex Sources" Regulation Sent to Illinois Pollution Control Board by DAPC on August 24, 1973

ABSTRACT

The Illinois Division of Air Pollution Control has conducted a series of air quality measurements at three shopping centers and a sports complex pursuant to obtaining information necessary to draft regulations regarding complex sources.

Data for these studies were collected during the peak traffic times for four days at each of the shopping centers and for one day at the Arlington Park Race Track. Data collected include ambient CO concentrations, wind speed and direction, and traffic data. Traffic data includes number of vehicles entering/leaving the facility, number of vehicles passing on adjacent roads, average speeds and distances traveled within the complex, etc. These data are and will be used to evaluate various approaches to determining the relationship between vehicle activity and CO concentrations. Two monitors were set up at each area; one at a place where heavy vehicular activity could be anticipated and another mobile monitor moved to locations in the parking lot as was judged appropriate. Data collected were reviewed from the standpoint of comparing those measurements at receptors subject to the roadway effect with simultaneous measurements at a receptor which was primarily subject to area-source influences. The data obtained show the roadway effect to be dominant therefore, the review criteria for the proposed regulation, used only to determine if a complex source is required to apply for a permit, are based on roadway effect considerations. Observed data were compared to air quality estimates made using (a) the Hanna Area-Source Model and (b) the HIWAY Model provided to Illinois DAPC by EPA. Some modifications to the HIWAY Model have been proposed. Data obtained from the monitoring studies were not given.

6 - SHOPPING CENTER

Study Title: AIR QUALITY AND NOISE INPUT OF THE CAPITAL CENTER DEVELOPMENT, BOISE, IDAHO

Sponsoring Agency: Boise Redevelopment Agency

Agency/Contractor (If Applicable):

Agency/Contractor (Performing Monitoring): Environmental Systems Laboratory
Sunnyvale, California

Report:

ABSTRACT

An eight-block downtown shopping center is proposed by the local Redevelopment Agency for Boise, Idaho. Since no air quality data exists for Boise, ESL has been meeting with regional and local EPA officials to draw up an air quality monitoring program which fulfills EPA requirements at minimum cost to the Redevelopment Agency. As well as air quality and noise monitoring, ESL is applying its computer models to predict future pollutant and noise levels in the vicinity of the shopping center area and throughout Boise. The resulting predictions will be the basis for design consulting to minimize adverse impacts.

Study Title: . . . AIR QUALITY IMPACT STUDY FOR EVERGREEN EAST SHOPPING MALL . . .

Sponsoring Agency: International Council of Shopping Centers

Agency/Contractor
(If Applicable):

Agency/Contractor
(Performing Monitor): Environmental Systems Laboratory

Report:

ABSTRACT

In the Seattle/Tacoma vicinity an extensive air quality monitoring program has been conducted to compare predicted air quality with observed air quality to verify and adjust a diffusion model developed for predicting air quality impact of traffic at a shopping center. A proprietary model has been validated at an existing shopping center and will be used to estimate air quality impact of future shopping centers.

Hourly averages of carbon monoxide concentration were measured at 12 sites around a shopping center for 16 hours each day. Meteorological data were collected on site and recorded for input to this model. Model development work has been conducted under supervision of Dr. Rossano at the University of Washington. Air quality measurements have been made by Environmental Systems Laboratory, Sunnyvale, California. It was not known at the time of this writing if a report of this study will be released by the sponsor.

Study Title:	OAKBROOK, ILLINOIS, SHOPPING CENTER
Sponsoring Agency:	International Council of Shopping Centers, N.Y.C.
Agency/Contractor (If Applicable):	Barton, Aschman Associates, Inc.
Agency/Contractor (Performing Monitoring):	Environmental Technology Associates, Inc.
Report:	

ABSTRACT

The Oakbrook, Illinois, Shopping Center air quality monitoring study measured carbon monoxide at four stations. The measurements were made in the shopping center parking lot and at an adjacent intersection. Associated traffic counts were made. Wind speed and direction were measured at the parking lot. Atmospheric stability categories will be estimated from cloud cover and wind speed data. Publication date for the report is estimated to be May or June 1974.

6 - SHOPPING CENTER

Study Title: AIR AND NOISE IMPACT OF ADDITIONAL DEVELOPMENT OF THE LLOYD CORPORATION PROPERTY, PORTLAND, OREGON

Sponsoring Agency: Private

Agency/Contractor (If Applicable)

Agency/Contractor (Performing Monitoring): Environmental Systems Laboratory
Sunnyvale, California

Report: ESL-ET67, Vol. I, March 1973
(Vol. III to be published March 1974)

ABSTRACT

The Lloyd Corporation, owner of extensive property in downtown Portland, has planned several additions to its Lloyd Center, a large regional shopping center. In response to the Department of Environmental Quality (DEQ), a state agency, a comprehensive environmental statement is being written for all projected developments through 1980. Essential elements of this study are ESL's use of existing noise and air quality data in Portland, acquisition of a limited amount of new data, and prediction of future air quality and noise levels. The pollutant measured was carbon monoxide, meteorological and traffic measurements were also made.

Study Title:	VEHICLE BEHAVIOR IN AND AROUND COMPLEX SOURCES AND RELATED COMPLEX SOURCE CHARACTERISTICS SUBTASK 1 - SHOPPING CENTERS
Sponsoring Agency:	Environmental Protection Agency
Agency/Contractor: (If Applicable)	
Agencv/Contractor: (Performing Monitoring)	GEOMET, Incorporated
Report:	Task Report under EPA Contract Number 68-02-1094 Task Order Number 3

ABSTRACT

The project consisted of a task, under a task order level of effort type of contract, to "collect, analyze and integrate technical data, and develop methodologies which can be used to provide guidelines for EPA and state agencies in reviewing and evaluating proposed new or expanded complex sources." The principal technical effort involved quantitatively relating the physical characteristics of each type of complex source to automobile movements, numbers, and engine running times or speeds.

For the six complex source types which involve parking facilities (shopping centers, airports, sports stadiums, parking facilities, recreational areas, and amusement parks), the methodology involved developing the concept of combining the numbers of cars operating, with a characteristic time of operation. Both of these parameters have characteristic and peak values depending on the type of source and its physical and operational characteristics; methods of calculation of appropriate values are given, to permit use in emission and air quality estimations.

For the seventh complex source (major highways), for which parking is not a factor, a different principle was developed for relating parameters descriptive of highway traffic to highway parameters. Briefly, one approximation technique which was developed, relates operating speed to design speed and the ratio of volume demand to capacity, and then evolves this into equivalent vehicle miles travelled. A more precise technique develops traffic density for specified highway segments, from volume demand and operating speed; emission rates can then be derived from consideration of unit emission rates, operating speed, and traffic density.

The seven methodologies have been used by EPA as the basis for guidelines which relate complex source characteristics to traffic behavior parameters (described above), thence to emissions, and finally to air quality estimates.

Study Title:	CARBON MONOXIDE MEASUREMENTS IN THE VICINITY OF SPORTS STADIUMS
Sponsoring Agency:	Environmental Protection Agency, Office of Air Quality Planning and Standards Monitoring and Data Analysis Division
Agency/Contractor (If Applicable):	
Agency/Contractor (Performing Monitoring):	Research Triangle Institute Research Triangle Park, Durham, N. C.
Report:	

ABSTRACT

The study was undertaken to obtain background data which would be useful in guaging the impact of sports complexes on ambient air quality. The data was also used to assess the performance of estimating methods proposed in the June 1973 Guidelines for Complex Sources. The monitoring was conducted during June and July of 1973 at the Atlanta and Pittsburg baseball stadiums. Seven days of monitoring were conducted at the Atlanta stadium which is in essentially flat terrain and four days of monitoring were conducted at the Pittsburg stadium which represented valley type terrain. In each stadium, three non-dispersive infrared carbon monoxide analyzers were set up upwind, downwind, and in the center of the stadium parking lot. In addition a series of 15 minute carbon monoxide grab samples were taken at four locations near major entrances during the period beginning one hour and fifteen minutes after the game. Traffic at four major entrances was recorded at five minute intervals during the same time periods and the time for randomly selected vehicles to enter and leave the parking lot was recorded. Meteorological measurements of surface wind speed, direction, and temperature were made within the parking lots.

Because of the relatively short time to fill or empty the parking lots the major air quality impact was on the hourly measurements. However, none of the observations indicated a violation of the one-hour NAAQS since the highest hourly concentrations observed were 22 ppm. in Pittsburg and 27 ppm. in Atlanta. A diurnal trend of background carbon monoxide concentrations not associated with stadium traffic was observed with the maximum concentration occurring between 0000 and 0600 hours. The eight-hour running average background concentrations nearly exceeded the eight-hour NAAQS of 9 ppm. during the early morning hours.

Although the number of observations are limited, a comparison of the observed and predicted values indicates that the proposed method for evaluating the maximum direct impact of complex sources on carbon monoxide concentrations appears appropriate for sports complexes. In all cases the agreement was within a factor of two and in most cases much closer than that.

Study Title:	TECHNICAL APPENDIX ___, AIR QUALITY AND NOISE IMPACTS FOR THE PROPOSED SANTA CLARA COUNTY SPORTS ARENA
Sponsoring Agency:	Santa Clara County, California
Agency/Contractor (If Applicable)	
Agency/Contractor (Performing Monitoring):	Environmental Systems Laboratory Sunnyvale, California
Report:	ESL-ET49

ABSTRACT

An environmental impact report (EIR) for the proposed Sports Arena was required in which three proposed sites were accorded equal and complete treatment. All three sites were within a triangle bounded by three heavily travelled highways.

For the air quality and noise elements of this study, ESL measured carbon monoxide, total and non-methane hydrocarbons, oxidant and noise at each site, meteorological and traffic measurements were also made. This data was related to historical data of the Bay Area Air Pollution Control District and to ESL's highway source model calculations, to characterize existing air quality and noise in the area. Predictions of future levels were then made based on future traffic, land use, and emissions. The EIR was submitted to the appropriate local agencies and jurisdictions. It is presently being employed in the decision on the final choice of site.

7 - SPORTS COMPLEX

Study Title: AUTOMOTIVE POLLUTION LEVELS NEAR VETERAN'S STADIUM
Sponsoring Agency: Air Management Services, City of Philadelphia
Agency/Contractor (If Applicable):
Agency/Contractor (Performing Monitoring): Air Management Services, City of Philadelphia
Report:

ABSTRACT

This study of air quality related to traffic arriving and departing from a sports complex has not been written up as a report. The information was obtained from an informal memo sent by the sponsor. Air quality was monitored at one location for 12 hours before and after a football game with a sell-out crowd attending the game. Total hydrocarbons, methane, and carbon monoxide were measured on the curb at an intersection just outside Veteran's Stadium from noon to midnight on the day of the football game. Wind speed and direction data are provided. Automobile traffic counts are not provided but adjacent parking lot capacities are known (12,167 cars) plus on-street parking can be estimated. Observed concentrations of carbon monoxide during peak pregame and postgame traffic was 10 to 20 times that observed during afternoon traffic. Total hydrocarbon concentrations doubled during peak traffic periods and no noticeable change was observed with methane concentrations.

Study Title:	. . . AIR QUALITY IMPACT OF LARGE TRAFFIC GENERATING COMPLEX SOURCES . . .
Sponsoring Agency:	County of Milwaukee, Wisconsin
Agency/Contractor (If Applicable):	
Agency/Contractor (Performing Monitoring):	County of Milwaukee, Department of Air Quality Control
Report:	Interoffice Memorandum, September 21, 1973

ABSTRACT

The County of Milwaukee is faced with the question of where to locate a new sports arena. Impact on air quality is one of the criterion which will be considered in the decision making process. In order to evaluate the potential impact the County Department of Air Quality Control made on-site carbon monoxide surveys in May and June 1973 at:

a. The Milwaukee County Stadium
b. State Fair Park
c. Lakefront Parking Area
d. Southridge Shopping Center

The observations made indicated neither the 1 hour or the 8 hour standards were exceeded at any of the four sites. Sampling was done during peak Friday afternoon and evening shopping hours; on a Sunday afternoon when 10,366 arrived at the State Fair Park. Meteorological data was not collected. Carbon monoxide detector tubes were used which provided a six minute sample time. Traffic data is provided.

7 - SPORTS COMPLEX

Study Title:	A MONITORING PROJECT TO EXAMINE THE RELATIONSHIP BETWEEN CO CONCENTRATIONS AND VEHICULAR ACTIVITY ASSOCIATED WITH COMPLEX SOURCES
Sponsoring Agency:	Illinois, Division of Air Pollution Control
Agency/Contractor (If Applicable):	
Agency/Contractor (Performing Monitoring):	Illinois, Division of Air Pollution Control (DAPC)
Report:	Information on Proposed "Complex Sources" Regulation Sent to Illinois Pollution Control Board by DAPC on August 24, 1973

ABSTRACT

The Illinois Division of Air Pollution Control has conducted a series of air quality measurements at three shopping centers and a sports complex pursuant to obtaining information necessary to draft regulations regarding complex sources.

Data for these studies were collected during the peak traffic times for four days at each of the shopping centers and for one day at the Arlington Park Race Track. Data collected include ambient CO concentrations, wind speed and direction, and traffic data. Traffic data includes number of vehicles entering/leaving the facility, number of vehicles passing on adjacent roads, average speeds and distances traveled within the complex, etc. These data are and will be used to evaluate various approaches to determining the relationship between vehicle activity and CO concentrations. Two monitors were set up at each area; one at a place where heavy vehicular activity could be anticipated and another mobile monitor moved to locations in the parking lot as was judged appropriate. Data collected were reviewed from the standpoint of comparing those measurements at receptors subject to the roadway effect with simultaneous measurements at a receptor which was primarily subject to area-source influences. The data obtained show the roadway effect to be dominant therefore, the review criteria for the proposed regulation, used only to determine if a complex source is required to apply for a permit, are based on roadway effect considerations. Observed data were compared to air quality estimates made using (a) the Hanna Area-Source Model and (b) the HIWAY Model provided to Illinois DAPC by EPA. Some modifications to the HIWAY Model have been proposed. Data obtained from the monitoring studies were not given.

7 - SPORTS COMPLEX

Study Title:	VEHICLE BEHAVIOR IN AND AROUND COMPLEX SOURCES AND RELATED COMPLEX SOURCE CHARACTERISTICS SUBTASK 3 - SPORTS STADIUMS
Sponsoring Agency:	Environmental Protection Agency
Agency/Contractor: (If Applicable)	
Agency/Contractor: (Performing Monitoring)	GEOMET, Incorporated
Report:	Task Report under EPA Contract Number 68-02-1094 Task Order Number 3

ABSTRACT

The project consisted of a task, under a task order level of effort type of contract, to "collect, analyze and integrate technical data, and develop methodologies which can be used to provide guidelines for EPA and state agencies in reviewing and evaluating proposed new or expanded complex sources." The principal technical effort involved quantitatively relating the physical characteristics of each type of complex source to automobile movements, numbers, and engine running times or speeds.

For the six complex source types which involve parking facilities (shopping centers, airports, sports stadiums, parking facilities, recreational areas, and amusement parks), the methodology involved developing the concept of combining the numbers of cars operating, with a characteristic time of operation. Both of these parameters have characteristic and peak values depending on the type of source and its physical and operational characteristics; methods of calculation of appropriate values are given, to permit use in emission and air quality estimations.

For the seventh complex source (major highways), for which parking is not a factor, a different principle was developed for relating parameters descriptive of highway traffic to highway parameters. Briefly, one approximation technique which was developed, relates operating speed to design speed and the ratio of volume demand to capacity, and then evolves this into equivalent vehicle miles travelled. A more precise technique develops traffic density for specified highway segments, from volume demand and operating speed; emission rates can then be derived from consideration of unit emission rates, operating speed, and traffic density.

The seven methodologies have been used by EPA as the basis for guidelines which relate complex source characteristics to traffic behavior parameters (described above), thence to emissions, and finally to air quality estimates.

Study Title:	ENVIRONMENTAL ANALYSIS FOR COMMERICAL RESIDENTIAL DEVELOPMENT IN MONTGOMERY COUNTY, MARYLAND
Sponsoring Agency:	Private
Agency/Contractor (If Applicable):	
Agency/Contractor (Performing Monitoring):	Environmental Systems Laboratory Sunnyvale, California
Report:	ESL-ET70, November 1973

ABSTRACT

An air and noise pollution analysis was conducted for a proposed development of residential and commercial properties in an urbanized portion of Montgomery County. The analysis was performed for the specific requirement of an administrative zoning hearing held by the County. Air quality monitoring of carbon monoxide was conducted at selected sites on and around the proposed development area. Meteorological and traffic measurements were also made. Specific attention was paid to characterize the air quality from major arterials adjacent to the site. Prediction of air quality and noise levels was conducted using models that ESL has developed applicable to roadway sources. Major emphasis was placed upon relating the predicted air and noise levels to federal and state standards and in performing mitigating design which would alleviate potential problems.

Study Title:	AIR QUALITY AND NOISE IMPACT OF THE CAPITAL CENTER DEVELOPMENT, BOISE, IDAHO
Sponsoring Agency:	Idaho Department of Highways and the Department of Environmental and Community Services
Agency/Contractor (If Applicable)	
Agency/Contractor (Performing Monitoring):	Environmental Systems Laboratory Sunnyvale, California
Report:	ESL-ET68 Vol. I, September 1973 (Vol. II to be published April 1974)

ABSTRACT

In the first major air quality monitoring program in Boise, Idaho, ESL is working with the Idaho Department of Highways (IDH) and the Department of Environmental and Community Services (DECS) to monitor carbon monoxide and meteorology. Information as to maximum and average CO levels is being gathered to provide a basis by which IDH can evaluate the impact for several of its near-term projects.

The monitoring tasks inlcude installation and maintenance of five stations monitoring ambient CO, lead, wind speed and wind direction. Of these stations one, centrally located, will be in operation for six months; the others will be operated in pairs for at least one month each. Continuous data will be supplemented by bag sampling near traffic sources and traffic counts will be made. The data will be reduced to one and eight hour values, and correlations between all stations will be computed. Meteorology from Boise airport (on a plateau above and about three miles from the central station) will also be included in the correlations.

As a result of this study, IDA and DECS are expected to be able to write and evaluate, respectively, air quality studies for most areas of Boise for near-term highway projects. The goal is a technical report which, combined with existing EPA publications and published tools, will allow them to accomplish this work.

Study Title: AIR QUALITY AND NOISE IMPACT RELATED TO THE SALEM-PEABODY STUDY
(Tasks A, B, and C)

Sponsoring Agency: Massachusetts Department of Public Works

Agency/Contractor:
(If Applicable):

Agency/Contractor
(Performing Monitoring): Environmental Systems Laboratory
Sunnyvale, California

Report: Task A, ESL-ET53, August 1973
Task B, ESL-ET54, August 1973
Task C, ESL-ET63, August 1973

ABSTRACT

The Salem-Peabody Study in Boston, Massachusetts comprised three separate efforts to provide a transportation plan for the area. ESL selected sites and monitored air quality, meteorology, traffic, and noise for all three efforts. Pollutants measured were carbon monoxide, total and non-methane hydrocarbons, and nitrogen oxides.

ESL staff met with EPA and Massachusetts Department of Public Works officials to discuss the impact found and produced technical reports detailing all work performed. Measures to mitigate adverse air quality effects were suggested.

Study Title:	LEAD CONCENTRATIONS IN DETROIT, NEW YORK AND LOS ANGELES AIR
Sponsoring Agency:	
Agency/Contractor (If Applicable)	
Agency/Contractor (Performing Monitoring)	
Report:	APTIC Abstract 10612L Lead concentrations in Detroit, New York and Los Angeles air. Preprint, General Motors Research Labs., Fuels and Lubricants Dept. and General Motors Industrial Hygiene, Dept., Warren, Mich., 24p., 1968. 18 Refs. (Presented at the 61st Annual Meeting of the Air Pollution Control Association, St. Paul, Minn., June 24-28, 1968. Publication GMB-773, Paper 68-90).

APTIC ABSTRACT

The concentrations of lead in air at 12 sites in Detroit, New York, and Los Angeles are reported. Sampling was carried out by filtration using a large "absolute" filter and equipment contained in a step-van truck. A portion of the filter was macerated in nitric acid and the lead determined spectrographically. The combined annual average lead concentration for four sites in metropolitan Los Angeles was approximately 40% higher than the combined averages of either the five sites in metropolitan New York or the three sites in metropolitan Detroit. Concentrations ranged from 0.4 micrograms/CU M at coastal Santa Monica, to 18.4 micrograms/CU M at a Los Angeles freeway interchange. Concentrations were generally highest in freeway areas, intermediate in commercial areas, and lowest in residential areas, and were about 40% higher in daytime than at night. Average lead concentrations were highest during autumn in New York and winter in Los Angeles reflecting an inverse realtionship with wind speed. Correlation coefficients between lead and carbon monoxide, at all sites, were statistically non-zero with 99% confidence, and varied from 0.75 to 0.96. Lead levels in road dirt were also measured and discussed. (Authors' abstract, modified).

Study Title: CARCINOGENIC AIR POLLUTANTS IN RELATION TO AUTOMOTIVE TRAFFIC IN NEW YORK

Sponsoring Agency:

Agency/Contractor (If Applicable):

Agency/Contractor (Performing Monitoring):

Report: APTIC Abstract 11028L
Carcinogenic Air Pollutants in Relation to Automotive Traffic in New York. Preprint, General Motors Research Labs., Warren, Mich., Dept. of Fuels and Lubricants, RP-GMR-777, 32p., 1968. 33 Refs. (Presented at the 61st Annual Meeting, Air Pollution Control Association, St. Paul, Minn., June 23-27, 1968. Paper 68-71.)

APTIC ABSTRACT

Sampling for particulates and carbon monoxide was carried out at tions of certain polynuclear aromatic hydrocarbons (Benzo(A)pyrene and Benz(A)anthracene) to automobile traffic. Carbon monoxide and lead were determined as indicators of air pollution from automotive combustion sources. Sampling equipment was contained in a step-van truck. Particulate matter was collected on a large "absolute" filter. The benzene extract (tar) was analyzed for benzo(A)pyrene and benz(A)anthracene utilizing column and reversed-phase paper chromatography in combination with ultraviolet spectro-photometry. The average concentrations of all pollutants were highest at Herald Square in Central Manhattan, and lowest in suburban Scarsdale. Concentrations of benzo(A)pyrene ranged from 0.1 micrograms/1000 CU M to 9.4 micrograms/1000 CU M, were higher than at night, and were highest in autumn and winter. For all sites considered together, the correlation coefficient of benzo(A)pyrene with carbon monoxide was 0.65, with lead, 0.74, and vanadium 0.54; all three correlations were statistically non-zero with 99% confidence. At individual sites, however some of these correlation coefficients were significant and others were not. Benzo(A)pyrene, in air, even in areas of greatest automobile traffic, appears related with both automotive and non-automotive sources (space heating). Benzo(A)pyrene concentrations at the Manhattan sites in New York were lower than previously measured in central Detroit, even though traffic was greater at the New York sites. BAP in New York was lower than reported for most U.S. cities, and more than reported for several European cities.

Note: This Abstract was reproduced "as is" from the APTIC survey. The omission of the second line was missing from the Aptic Abstract when received.

Study Title:	THE AUTOMOTIVE CONTRIBUTION TO AIR-BORNE POLYNUCLEAR AROMATIC HYDROCARBONS IN DETROIT
Sponsoring Agency:	General Motors Research Laboratories
Agency/Contractor (If Applicable):	
Agency/Contractor (Performing Monitoring):	General Motors Research Laboratories Warren, Michigan
Report:	JAPCA 15(3) pp. 113-22 March 1965

ABSTRACT

The aim was to determine the contribution by automotive vehicles to the polynuclear aromatic hydrocarbons in city air. Sampling of particulate matter at the rate of 140 cu m/min 5000 (CFM) was carried out at two heavily-trafficked sites in Detroit and one suburban site in Warren, Michigan. Carbon monoxide was determined continuously, and particulate matter was analyzed for "tar," polynuclear aromatic hydrocarbons, lead, vanadium, and sulfates. Polynuclear aromatic hydrocarbons in automobile exhaust gas are assumed to be dispersed in air along with carbon monoxide or lead from automobiles. It is further assumed that automobiles are the sole source of carbon monoxide and lead in the atmosphere. Concentrations of carbon monoxide and lead in exhaust gas and in the air are utilized to estimate the percentage of polynuclear aromatic hydrocarbons in the air attributable to automobiles. The mean automobile contributions to benzo(a)pyrene in the air, based on lead concentrations, were 18% at a freeway interchange, 5% in a downtown commercial area, and 42% in suburban Warren. The average concentrations of benzo(a)pyrene at the sites were 6 micrograms/1,000 cu m, 7 micrograms/1,000 cu m and 1 microgram/1,000 cu m, respectively. Mean contributions based on carbon monoxide concentrations were approximately twice the levels based on lead concentration Benzo(a)pyrene and Benz(a)anthracene in air were not statistically related to carbon monoxide or lead in air, but were higher in winter than in summer, probably because of the higher levels of these materials emitted in space heating combustion in winter. (Authors abstract modified).

Study Title: ENVIRONMENTAL ANALYSIS OF PROPOSED NEW YORK CITY CONVENTION AND EXHIBITION CENTER

Sponsoring Agency: New York City Convention and Exhibition Center

Agency/Contractor (If Applicable):

Agency Contractor (Performing Monitoring): Environmental Systems Laboratory
Sunnyvale, California

Report: ESL-ET62, November 1973

ABSTRACT

The proposed Midtown Convention Center in New York City represents a project with potentially significant traffic related impacts. In the air quality study, ESL combined a monitoring program with statistical analyses of past air quality data in New York. The monitoring program measured ambient CO, NO_2, and oxidants. Meteorological and traffic measurements were also made. The monitoring program was also employed to calibrate ESL's urban street canyon dispersal model.

Predictions of future air, noise and water quality were calculated for both build and no build and for conditions leading to least, most probable, and greatest impact. For these conditions varying growth rates were assumed; in addition vehicle emissions were calculated for three different features of the emission control program. Material for the final environmental impact statement is being prepared.

Study Title: CARBON MONOXIDE DETERMINATIONS IN SUBTERRANEAN CARPORTS

Sponsoring Agency:

Agency/Contractor (If Applicable):

Agency/Contractor Performing Monitoring):

Report: APTIC Abstract 09010
Carbon monoxide determinations in subterranean carports. ((Kohlenoxidmessungen in unterirdischen autoeinstellhallen.)) Chfm. Rundschau (Solothurn), 17(26):1-8, 1964. 5 references translated from German. Joint publications research service, Washington, D. C., R-8937-D, 13P., Jan. 12, 1968.

APTIC ABSTRACT

CO determinations with a recording infrared spectrograph are reported. The measurements pertain to ventilated garages and garages without ventilation systems in the city of Zurich. The CO concentrations in ventilated garages are in the average (for a 10-hour measurement period) below 60 cc CO/CU.M. Individual short-term peak values of more than 500 ppm could be occasionally observed. The values determined in an unventilated garage with approximately 70 to 90 parking spaces ranged in the average from 90 to 100 ppm and the peak values reached a height of more than 500 ppm CO. (Author's summary)

Study Title: LINCOLN CENTER GARAGE ENVIRONMENTAL EXPOSURES

Sponsoring Agency: Department of Air Resources, New York City

Agency/Contractor (If Applicable):

Agency/Contractor (Performing Monitoring): Department of Air Resources, New York City

Report: Interoffice Memorandum (Dept. of Air Resources, New York City)

ABSTRACT

On Thanksgiving Day, November 23, 1972 a number of people experienced symptoms of being overcome or were overcome due to exposure to high levels of carbon monoxide while waiting in their automobiles to leave the parking garage. The Department of Air Resources installed carbon monoxide monitoring equipment in the garage the following day to measure the CO levels in the garage. Data reported in the memo that was furnished showed a maximum 1 hour average concentration as high as 71-85 ppm. Data for other hours on Saturdays and Sundays showed 1 hour maximums of 46-42 ppm. and maximum 8 hour averages of 18-42 ppm.

The high levels of CO on the Thanksgiving Day weekend were attributed to traffic conditions on 65th street which did not permit automobiles to exit from the garage freely and thereby caused auto's to idle in the garage for long times. Also, possibly the ventilation system was not being used to its capacity.

Expected dosage levels to persons exposed to high levels of CO for short periods of time are given and comparison is then made in terms of the expected carboxyhemoglobin levels of the blood. Recommendations to avoid the high levels of CO in the garage in the future are listed.

Study Title:	DRAFT ENVIRONMENTAL IMPACT REPORT TO THE CITY OF MOUNTAIN VIEW SUBJECT: PROPOSED DEVELOPMENT AT 266 ESCUELA STREET
Sponsoring Agency:	Private
Agency/Contractor (If Applicable):	
Agency/Contractor (Performing Monitoring):	Environmental Systems Laboratory Sunnyvale, California
Report:	ESL-ET45 March 1973

ABSTRACT

An environmental impact statement was written by ESL for a residential tract in Mountain View, California. Since the development was near U.S. 101, a major highway with a projected Average Daily Traffic of 185,000 vehicles, air quality and noise were the major issues. Both air quality and noise were monitored at the site during this project. The pollutant monitored was carbon monoxide. Meteorological measurement and traffic measurements were also made. ESL assisted the developer in designing a phased construction plan, in which houses will be built nearer the roadway as future emission controls take effect.